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Damage Stability Issues for the Advanced Double Hull (ADH) Project

By
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The U.S. Navy is currently investigating the concept of an advanced, unidirectionally framed, double hull surface combatant ship design. This report documents the results of an investigation into the damage stability issues involved. Comparisons have made between a conventional monohull surface combatant and the vessel modified with double hull compartments. Double hull configurations internal and external to the original hull shell using three foot and six foot spacings were considered. Several watertight compartmentation geometries within the double hull spaces were also investigated. The Ship Hull Characteristics Program (SHCP), version 4.11 was used for intact and damaged stability calculations. Damage conditions evaluated were specified by Navy Design Data Sheet (DDS) 079-1 dated 1 August 1975, for the stability and buoyancy requirements for U.S. naval surface ships. The stability criteria as specified in DDS 079-1 were applied and evaluated for the double hull CG 47 computer models. Additional damage conditions and stability criteria evaluated were taken from the U.S. Coast Guard standards adopted for double hull oil tankers. It is concluded that the double hull concept does have an adverse effect on damage stability and that the existing Navy stability criteria is adequate for double hull combatants.

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ABSTRACT

The U.S. Navy is currently investigating the concept of an advanced, unidirectionally framed, double hull surface combatant ship design. This report documents the results of an investigation into the damage stability issues involved. Comparisons have made between a conventional monohull surface combatant and the vessel modified with double hull compartments. Double hull configurations internal and external to the original hull shell using three foot and six foot spacings were considered. Several watertight compartmentation geometries within the double hull spaces were also investigated. The Ship Hull Characteristics Program (SHCP), version 4.11 was used for intact and damaged stability calculations. Damage conditions evaluated were specified by Navy Design Data Sheet (DDS) 079-1 dated 1 August 1975, for the stability and buoyancy requirements for U.S. naval surface ships. The stability criteria as specified in DDS 079-1 were applied and evaluated for the double hull CG 47 computer models. Additional damage conditions and stability criteria evaluated were taken from the U.S. Coast Guard standards adopted for double hull oil tankers. It is concluded that the double hull concept generally does have an adverse effect on damage stability and that the existing Navy stability criteria is adequate for double hull combatants.

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INTRODUCTION

The concept of a double hull surface combat vessel raises the possibility of the application of several different technologies. Acoustic advantages can be obtained by filling the double hull space with fluid and acoustic foam; weapons effects can be minimized by providing a stand off distance between the outside world and the inside equipment, ordinance, and personnel; damage control advantages are obtained from increased counterflooding possibilities; and ship construction can be more efficient and cost effective. However, as the U.S. Navy has not designed or constructed a double hull combatant vessel, there are many unanswered questions which must be addressed early in the design cycle. In fact, the stability characteristics of double hull vessels are not addressed in U.S. Naval design guidelines.

This report documents an investigation of the stability issues involved with the design of a double hull surface combatant. The basis for the investigation was a computer model of the CG 47 hull form and it's internal

compartmentation. The double hull version of the CG 47 has been modeled with double hull compartments internal and external to the original hull shell using three foot and six foot spacings. Several different watertight compartmentation geometries within the double hull spaces were investigated. The Ship Hull Characteristics Program (SHCP), version 4.11 was used to model intact and damaged stability characteristics. Damaged conditions and stability criteria evaluated were specified by naval design guidelines for standard monohull combat vessels. Additional damage conditions and stability criteria evaluated were taken from the U.S. Coast Guard standards adopted for double hull oil tankers. Evaluation of the stability criteria was performed using a new software tool developed specifically for this task.

COMPUTATIONAL SHIP MODEL DESCRIPTION

The CG 47 was selected as the baseline hullform to be used in this investigation. The SHCP representation of the CG 47 hull form and internal compartmentation was provided by the Naval Sea Systems Command [1] . The input file, originally provided in SHCP version 3 format, was modified for use with SHCP version 4.11. The newer version of SHCP was used because of an updated compartmentation description format which made modeling of the double hull compartments easier.

The double hull modifications to the original CG 47 SHCP input file were made in the simplest manner possible. Because of the modeling complications in the presence of appendages and significant changes in the shape of the hull form at the ends of the vessel, it was considered adequate for the level of detail necessary, to limit the double hull to the central length of the ship hull. The double hull used in this investigation was created between stations 5 and 16, tapering down to original CG 47 shell at stations 3.97 and 17 respectively. These station numbers were selected from the station offset list provided in the original input file and allowed the longest extent of maximum double hull space. Figure 1 shows a schematic of the hull form indicating the area covered by the double hull space.

In addition to the external double hull shell spacings of 3 feet and 6 feet, two other shell spacings of the same size were used internal to the original hull shell. Each double hull was created from the existing hull shell by projecting the original offsets normal to the hull shell by the appropriate distance. In all cases, the base line remained constant as did the location of the vertical center of gravity and draft. In order to maintain an even keel condition, the longitudinal center of gravity was allowed to move. Table 1 shows the ship particulars for the original hull form and external double hull variants. Body plans are shown in Figure 2.

The internal compartmentation of the original CG 47 was not affected by the addition of the external double hulls. However, the internal double hulls did impact the internal compartmentation. No attempt was made to rearrange the compartments to account for the lost internal volume. Certain compartments were lost completely to the double hull space while others lost portions of their usable volume. A true double hull modification, if undertaken, would redistribute compartments in a much more logical and practical manner. This would not be a trivial task and was not considered to be appropriate for the level of detail desired for this investigation.

DOUBLE HULL COMPARTMENTATION GEOMETRIES

Each double hull space was separated by transverse watertight bulkheads located at the same locations of those within the original vessel. Figure 3 shows the fore and aft compartment extents from the original CG 47 input file. The clustering of points indicates the locations of the main bulkheads. Within each longitudinal section of the double hull spaces, it has been assumed that there was no tankage or large machinery and the space was void (permeability 0.98). Figure 4 shows a schematic of the four double hull compartmentation geometries investigated; J tank, U tanks, wing tanks, and segmented tanks. Each geometry, when used, was applied to all of the double hull spaces. The combination of the original CG 47 and four double hull spacings (internal/external), and the four compartmentation geometries yields 17 different vessels for the investigation.

STABILITY CRITERIA AND DAMAGE CONDITIONS USED

As part of the stability task, a review of the existing U.S. Navy stability criteria was performed. A review of pertinent stability information from the commercial shipping industry, particularly double hull oil tankers, was also included.

U.S. NAVY REGULATIONS

The U.S. Navy stability criteria for both intact and damaged conditions are covered in Reference [2]. The Design Data Sheet includes monohull combat and auxiliary vessels, SWATH's, hydrofoils, and most other forms of surface vessel in the U.S. Navy fleet and specifies the types of damage to be investigated. There are currently no provisions for the special case of double hull construction for combatant or auxiliary vessels.

The intact criteria for surface vessels includes the cases of a 100 knot beam wind, the lifting of heavy weights over the side, towline pull (tugs), personnel crowding to one side, high speed turning, and ice loading. For combatant vessels, only the beam wind, high speed turning, and possibly ice loading conditions need be investigated. For comparative purposes, it is sufficient to consider only the wind loading condition.

Figure 5 shows an example intact righting arm curve and wind heeling arm curve. The point B is the wind loaded static heel angle, the point C shows the angle at the maximum righting arm, and the angle θ_r is the roll back angle. The roll back angle is defined to be 25 degrees and represents a mean maximum angle that the vessel would roll back when in waves. For the intact case, the maximum permissible heel angle, as indicated by point D, is the angle at which the righting arm becomes negative or 90 degrees, whichever comes first. Note that the wind heeling arm shown is positive through the range of heel angles shown. Assuming the center of wind pressure is located above the vessel center of gravity, this would indicate a positive heeling moment caused by wind blowing across the deck from port to starboard. Wind blowing across the deck from starboard to port would produce a negative heeling moment and the wind heeling arm curve would be negative (ie, mirrored across the x-axis).

The intact criteria, under wind loading is given by two conditions. The righting arm value at the static wind loaded heel angle (point B in Figure 5) shall be no more than 60% of the maximum righting arm value (point C in

Figure 5). This condition insures that the static heel angle in the presence of high wind does not approach the point of diminishing stability. The second condition is that the ratio between the shaded areas (A1 and A2 in Figure 5) is no less than 140%. This condition insures that there is adequate righting energy to keep upright while being acted upon by wind and waves.

The Design Data Sheet specifies the type and amount of damage to be considered. For combat vessels, a shell opening of 15% of the length of the vessel, on one side (port or starboard), from centerline to main deck is specified. This 15% length may occur at any longitudinal position. For this investigation, only successive 15% lengths are considered. The other damage condition specified is weapons damage. The exact nature of the weapons damage and the size of the opening is in practice, classified. However, for this investigation, the damage condition used in a dynamic damaged stability model test study[1] will be used, in a slightly modified form . In this scenario, the damage occurs such that all interior compartments between stations 14.44 and 19.13 were flooded. An additional weapons damage condition is used here which had only a starboard side opening between stations 14.44 and 19.13.

Figure 6 shows an example of a damaged condition righting arm curve and wind heeling arm. This figure is similar to Figure 5 except that the undisturbed static heel angle shown as point A has moved away from the zero angle point. In the damaged condition, the roll back angle and wind speed are reduced according to functions of ship displacement (both specified in the DDS). The same criteria from the intact case applies to the damage case with the addition of a minimum difference between the maximum righting arm value and the wind heeling arm at that heel angle (0.275 ft minimum). There is also a maximum permissible static wind loaded heel angle. The value specified depends on weather the ship is equipped with a side protection system (15 degrees without and 20 degrees with). The side protection system is basically voids on the sides of a ship which are dedicated solely to counterflooding in a damaged condition. Aircraft carriers and other larger vessels are so equipped. If a ship is equipped, then the counterflooding capabilities must be able to reduce the static loaded heel angle to less than 5 degrees.

In the damaged condition, the maximum permissible heel angle, θ_d, is defined as the downflooding angle where there is free communication between internal spaces and the sea. For this investigation, the maximum permissible heel angle will be considered to be the angle at which the deck at edge becomes immersed. In reality, the fan tail deck near the stern has lower sheer line than the rest of the vessel and will usually be the first deck to become immersed; however, it is current practice to assume that there are no permanent openings on the aft deck. For this investigation, only the deck at edge forward of station 17 will be used for determining the maximum permissible heel angle.

The double hull spaces could easily qualify as a side protective system if they are indeed left as dedicated counterflooding spaces (not all spaces would need to be dedicated). The U-tank geometry would not be appropriate for a side protective system because of the inherent inability to generate an additional heeling arm when flooded. The segmented compartment geometry, on the other hand, can generate heeling arms to reduce the static heel but at the

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[1] Documented in a limited distribution report.

cost of associated piping and pumping systems. There is therefore a design trade off between the complexity of highly segregated double hull compartments and the associated piping and pumping, and the accompanying increase in damage control options. The damage control options for each geometry and the effects of counterflooding are not addressed further by this investigation.

U.S. COAST GUARD REGULATIONS

The commercial oil industry has put much effort into investigating double hull oil tanker design issues, including the stability characteristics. This was a direct result from public pressure to minimize the environmental impact of tanker damage. The U.S. Coast Guard (USCG) has addressed the stability considerations in an informal working document [3]. The efforts of the USCG, the major oil companies, and other marine groups went into the drafting of these standards and criteria. In practice, the double hull oil tanker criteria have no relation to naval combat ships, but they do provide a different view of damage stability criteria and evaluations. The differences between the USCG and naval stability criteria are highlighted by the different measures of merit used and damage conditions specified. The USCG criteria addressed here are only the additional criteria applicable to double hull tankers and not the standard USCG stability criteria [4].

Figure 7 shows another example of an intact righting arm curve. The metacentric height (GM) is to be no less than 1.5m (4.92 ft). In this investigation, the metacentric height is calculated from the righting arm curve by a line tangent to the curve at the static heel angle (zero in the intact case). The value of the righting arm taken from the tangent line at π radians (57.3 degrees) of heel beyond the static heel angle is the metacentric height [5]. The righting arm at 30 degrees heel shall also be greater than 0.2m (0.656ft) with the maximum righting arm occurring at a heel angle greater than 25 degrees. The righting energy, which is the area under the righting arm curve, shall be greater than 0.055 m-rad up to 30 degrees heel, 0.03 m-rad between 30 and 40 degrees, and 0.09 m-rad up to 40 degrees heel or the downflooding angle, which ever is less.

Figure 8 shows an example of a damaged condition righting arm curve. For the damage condition, the static heel angle (without wind loading) shall be less than 25 degrees. The righting arm shall also be positive for no less than 20 degrees beyond the static heel angle. In addition, the righting energy shall be greater than 0.0175 m-rad. The damage conditions specified by the USCG criteria includes bottom raking and side raking. For this investigation, only bottom raking was considered since the Navy specified 15%L damage conditions serve a similar function and are geometrically similar to side raking. The regulations specify raking lengths of either 40% or 60% of the length of the vessel, starting at the forward perpendicular, depending on displacement. For this investigation though, bottom raking damage resulting in 20%L, 40%L, and 60%L shell openings (starboard side only) was used.

SHCP STABILITY RESULTS

The results of SHCP computer runs are tables of righting arm, transverse, longitudinal, and vertical center of buoyancy, draft, and trim as functions of heel angle. For this investigation, the vessel was allowed to sink and trim as necessary in all conditions. A total of 207 separate righting arm curves were calculated for this investigation.

Plots of the righting arm, draft, and trim for the intact condition are shown in Figure 9 for the original hullform and the two external double hull variants. The intact case indicates the differences in stability characteristics due only to the additional volume distributed along the hull for the external double hull variants. Up to approximately 30 degrees heel, there is little difference in righting arm between the hullforms. Past 40 degrees of heel, the larger double hull losses righting energy rapidly. However, the larger external double hull provides more buoyancy (due to the additional volume) which is reflected in the smaller loss of draft and smaller trim angles as compared to the original hull form.

Righting arm curves for the sequential 15%L damage conditions are shown in Figures 10 through 21. Figure 10 for the first 15% length from station 0 to station 3 shows the righting arm, draft, and trim for the original hull form and the external double hull variants. This is due to the double hull beginning aft of station 3. The remaining figures show the righting arms only. There are two figures for each 15%L damage condition which allow separate comparison of the effect of double hull compartmentation geometry and double hull shell spacing.

Figures 22 and 23 show the righting arm curves for the severe weapons damage condition with both port and starboard side flooding. Figures 24 and 25 show the righting arm curves for the severe weapons damage condition with only starboard side flooding. The two figures shown for each damage condition display, separately, the effect of double hull compartmentation geometry and double hull shell spacing. In several of these damage scenarios, the severity of the flooding results in either deep drafts (large sinkage) or large trim angles or both.

Figures 26 through 31 show the righting arm curves for bottom raking damage. Shell openings of 20%, 40%, and 60% of the length are shown with two figures for each damage condition.

STABILITY ANALYSIS

The analysis of the stability results, as represented by the righting arm curves, has been performed using the established criteria previously discussed as a series pass/fail tests. In addition, the degree of pass or fail for a given criteria is also evaluated. All assumptions stated previously regarding the deck at edge immersion and downflooding angles have been incorporated into an analysis computer program written specifically for this task.

INTACT CONDITION

The intact stability evaluation results are listed in Table 4. Damage stability evaluation results for all design variants and the original CG 47 are listed in Tables 5 through 21. The intact table contains the same information as shown in the damage stability tables except for the deck at edge immersion angles and corresponding station number found to be immersed, and positive stability range information.

Tables 22 through 34 give a summarized listing of the stability evaluations for each criteria. The tables show the difference between the computed values for each geometry and the criteria value. Negative values indicate

a criteria failure. The greater the magnitude of the value in the table, the further it is from the criteria value. These tables therefore may be used to indicate relative differences between the different geometries investigated.

Figure 32 shows the results of the intact stability analysis using the U.S. Navy criteria. Both criteria are passed for each external double hull shell spacing. Inspection of the righting arm curves in Figure 9 shows the smaller maximum righting arm values for the double hull variants which explains the increase in righting arm ratio (since nearly identical static wind loaded static heel angles). The decrease in area ratio for the two double hulls is due to the smaller heel angles for deck at edge immersion which cuts off the A1 area before the decrease in righting arm curves occur (beyond 40 degrees heel).

Figure 33 shows the results of the intact stability analysis using the USCG criteria set. The metacentric height criteria fails in all cases. However, the minimum value specified is a reasonable value for a full shaped oil tanker design, while surface combatant vessels are finer hullform designs which tend to have lower metacentric heights. The other results shown indicate small differences in righting arms and quicker deck at edge immersion for the larger double hull spacing.

The intact stability characteristics discussed are not specific to the double hull per se. They simply show the differences in stability due to the addition of volume external to the existing CG 47 hull form. The additional volume has no direct relation to a double hull since the addition could just as easily be crew berthing as void compartments. This also tends to complicate the damage stability analysis since stability characteristics for the external double hull geometries investigated are partially due to the external volume addition as well as the double hull compartments.

15%L DAMAGE CONDITIONS

Area ratio results for the 15%L damage conditions are plotted in Figure 34. It can be seen that as the damage location is moved aft, there is a decrease in the area ratio for all geometries investigated. However, with the damage located between stations 9 and 12, there is a slight increase in area ratio. This is due to the large volume of symmetric flooding within the engine room area, which results in decreased static heel. For damage located between stations 15 and 18, there is an obvious grouping of reduced area ratio for all geometries. This is a direct result of the highly asymmetric nature of internal compartmentation of ship spaces contained between station 15 and 18. In the real world, these compartments would utilize cross flooding vents to achieve a more symmetric flooding condition and hence, a reduced static heel angle. In several cases, the area ratio is negative which is due to the static heel angle under wind loading exceeding (or being very close to) the deck at edge immersion angle. In all cases it is observed that the degree of excedance of the area ratio criteria is directly related to the degree of asymmetry of flooding.

Figure 35 shows the wind loaded static heel angles for all of the 15%L damage conditions. Like the area ratio criteria discussed above, wind loaded static heel is directly related to the degree of flooding asymmetry. For the U-tank geometry cases, the wind loaded static heel (and undisturbed static heel) is slightly smaller than the original CG47.

Righting arm ratio results for the 15%L damage conditions are shown in Figure 36. This criteria is more sensitive to reduced righting arm resulting from lost buoyancy due to flooding, and not very sensitive to the degree of

asymmetry of flooding. The external double hull geometries, having the most righting arm reduction, therefor tend to have larger righting arm ratio values than any internal double hull geometry. Only one righting arm ratio criteria exceedance was observed, for the external 6 foot double hull with the U-tank geometry.

Figures 38, 39, and 40 show plots of the USCG criteria for maximum allowable static heel angle, range of positive righting arm range, and righting energy. All geometries passed the USCG criteria with the exception of the two 6 foot U-tank geometries which exceeded the 25 degree static heel angle criteria.

WEAPONS DAMAGE CONDITIONS

The area ratio results for the two weapons damage conditions are shown in Figure 41. Only the original hull form, with symmetric damage, has a positive area ratio value (below the criteria limit). For this set of damage conditions, the wind loaded static heel angles shown in Figure 42, is quite high. In most cases, the static wind loaded heel angle exceeds the deck at edge immersion angle. Surprisingly, the area ratio values are lower for the external double hull variants than for the internal double hull variants.

Figure 43 shows the righting arm ratio results for the two weapons damage conditions. There is little variability in values for each double hull variant except for the external double hull with starboard side damage which shows larger values for the more asymmetric compartmentation geometries. The only observed righting arm ratio criteria failure is for the 6 foot external double hull with segmented compertmentation subjected to starboard side damage.

Figure 44 shows plots of the difference between the maximum righting arm and the wind heeling arm at the same heel angle. No criteria violations are observed.

Figures 45, 46, and 47 show plots of the static heel angle, positive righting arm range, and righting energy results for the two weapons damage conditions. It is surprising to see that these two severe damage conditions pass all of the USCG double hull criteria for all of the geometries considered. The J-tank and segmented tank geometries do however come quite close the maximum allowed static heel angle of 25 degrees, starboard side damage only.

BOTTOM RAKING DAMAGE CONDITIONS

Area ratio results for the bottom raking damage conditions are show in Figure 48. All of the J-tank geometries, the internal 6 and external foot wing tank, and the 6 foot external segmented tank geometry fail the criteria for 60%L damage. The 6 foot external J-tank variant also fails for 40%L damage. The degree of exceedance ranges from slight (for the internal 3 foot J-tank) to severe (for the 6 foot shell spacing geometries which fail). The more severe criteria failures occur with the static wind loaded heel angle exceeding the deck at edge immersion angle.

The wind loaded static heel angle is plotted in Figure 49 for the bottom raking damage conditions. The maximum allowable values are exceeded by all cases with failed the area ratio as discussed above. The remaining segmented tank geometry cases also exceeded the maximum static wind loaded heel angle limits. The plots in Figure 49 show that larger wind loaded heel angles are obtained for the J-tank and segmented tank geometries and that they increase rapidly with bottom raking damage length.

Figure 50 shows the righting arm ratio results for the bottom raking damage conditions. All geometries pass the criteria. Only the external 6 foot J-tank geometry case shows significant differences from the other geometries. Figure 51 shows the difference between the maximum righting arm and the wind heeling arm at the same heel angle. Again, all geometries pass the criteria with only the J-tank geometries (all shell spacings) showing significant variation from the trends.

The static heel angles for the three bottom raking damage conditions are shown in Figure 52. Only the 6 foot shell spacing, J-tank geometry cases, for 60%L damage, exceed the USCG maximum of 25 degrees. The observed trend are interesting to note. For 20%L damage, all cases are very similar, which is to be expected as the double hull covers a small portion of the first 20% of the length. At 40%L damage, the J-tank and segmented tank geometries are clearly heeling more than any of the others. At 60%L damage, the J-tank geometry exhibits much more heel than any other geometry and the wing tank geometry has begun to show more static heel angle. In all cases, the U-tank geometry and original hull remain close to zero static heel. Figures 53 and 54 show the righting arm range and righting energy results. No criteria failures are observed.

CONCLUSIONS

An evaluation of the stability characteristics of a double hull surface combatant vessel has been carried out. A conventional monohull and several different double hull compartment geometries have been included in the evaluation. Current U.S. Navy stability criteria and imposed damage conditions were used for comparing the results. In addition, the U.S. Coast Guard stability criteria and imposed damage conditions for double hull oil tankers were included. The Navy's standard computer program for stability calculation, SHCP version 4.11 was used to perform all calculations. The evaluation of the SHCP generated stability characteristics and comparisons to the criteria was performed using a newly developed software tool.

Results for the evaluations can not be considered in a fully quantitative sense because of the assumptions made about the particular vessel and the double hull modifications, as well as the interpretation of the stability criteria for the level of design detail used. However, trends can be identified and conclusions drawn from them.

The addition of double hull compartments to a conventional surface combatant vessel results in a complicated interaction between the righting arm and heeling condition under external loading. Depending on the extent of damage and the compartmentation geometry used, the double hull versions tend to have slightly larger righting arms but at the cost of larger static heel angles. The geometry of the compartmentation within the double hull also tends to be a more important factor than the between hull spacing. The segmented compartmentation and J-tank geometries which encourage longitudinally asymmetric flooding are generally worse (in terms of criteria evaluation) than wing tank and U-tank geometries which encourage symmetric flooding. There is a trade off though between smaller static heel angles when the flooding is symmetric and the increased counterflooding options for damage control purposes associated with the asymmetric compartmentation. While not addressed in this investigation, the dynamic effects of water in the double hull compartments may also favor a more compartmented geometry.

The U.S. Navy damage stability criteria differentiates between vessels with and without side protective systems. This translates into dedicated counterflooding compartments. The double hull could easily be considered a side protective system if the decision is made to dedicate the space to counterflooding. Effective counterflooding requires some degree of longitudinal segmentation of the double hull space. The benefit would be a slightly less restrictive criteria but the cost is the complexity of the additionally pumping and piping systems associated with the counterflooding capability. In addition, the proposal of "floating decks" within the ship should be investigated to insure that flooding or fire fighting water does not transfer between decks which would tend to adversely effect stability. These issues should be addressed by the damage control task of the ADH Project.

The current U.S. Navy stability criteria is adequate for the task of evaluating double hull surface combatant vessels. No modifications are necessary although there is room for clarification. Margin line immersion limitations and the roll back angle used for computing an area ratio are meant to ensure that there is adequate reserve righting arm to prevent extreme excursions in roll or even capsizing when the vessel is damaged. This investigation has shown cases where the static heel angle under the effect of wind approaches the angle at which the deck at edge becomes immersed and some cases, is beyond that angle. The result is either a negative area ratio at one extreme or a very large area ratio at the other. The large ratio would pass the criteria test, however, it is not an acceptable situation. The definition of the area ratio should therefore be modified so that this situation is explicitly excluded from passing the test. A possible addition to the Navy stability criteria might be a bottom or side raking condition. This addition would ensure proper stability characteristics in the event of grounding damage or relatively light ordinance damage which only ruptures the outer hull shell.

It has been noted during this investigation that there is some discrepancy between the U.S. Navy criteria as currently worded and the interpretation of the criteria in practice. It is suggested that the Design Data Sheet be amended to provide some form of explicit guidance on the interpretation of the criteria and under what circumstances certain criteria might be relaxed. It is impossible to cover every conceivable type of design which might arise in the future but it is also important to provide instructions on application of criteria in these events. This is the reason that this investigation was performed in the first place.

Having performed this analysis using an existing vessel with a series of contrived double hull modifications, the stability results presented may paint a bleaker picture than reality would display. Performance of an actual ADH design could be much better than a retrofit design of an existing vessel. However, this study does not necessarily support that hypothesis, nor disprove it either. Still, there is no reason to believe that an ADH combatant design can not be developed which exhibits acceptable stability characteristics.

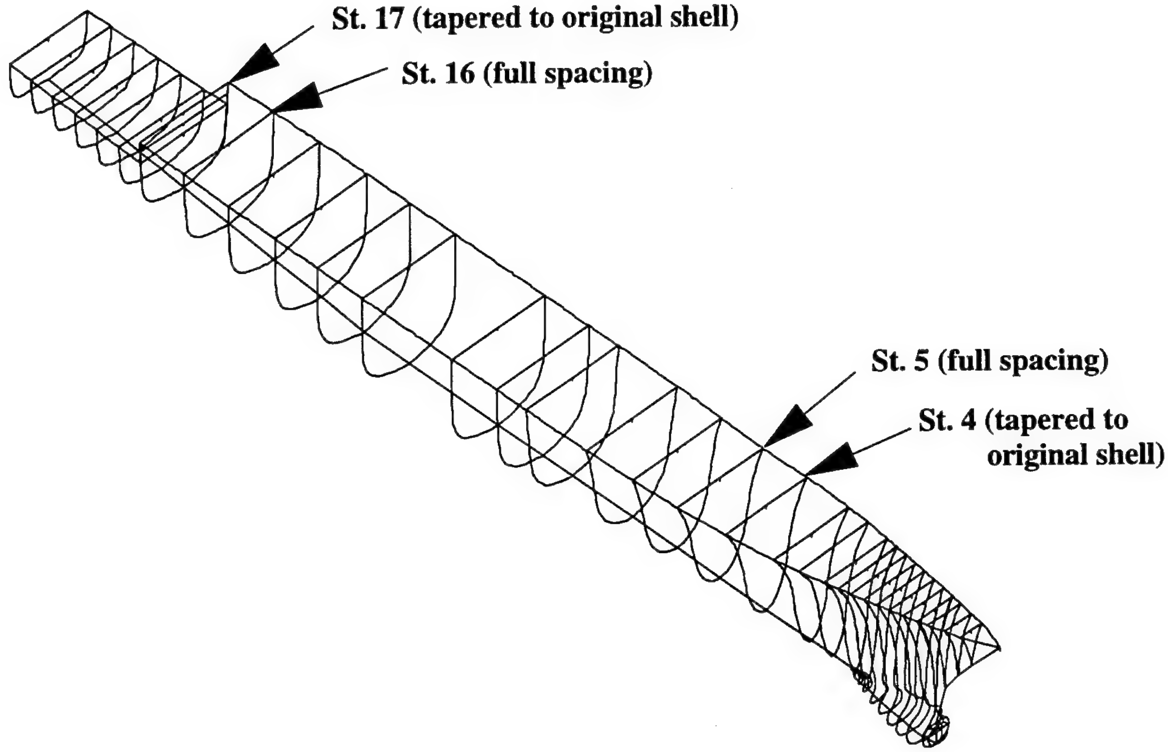


Figure 1. Location of Double Hull Modifications

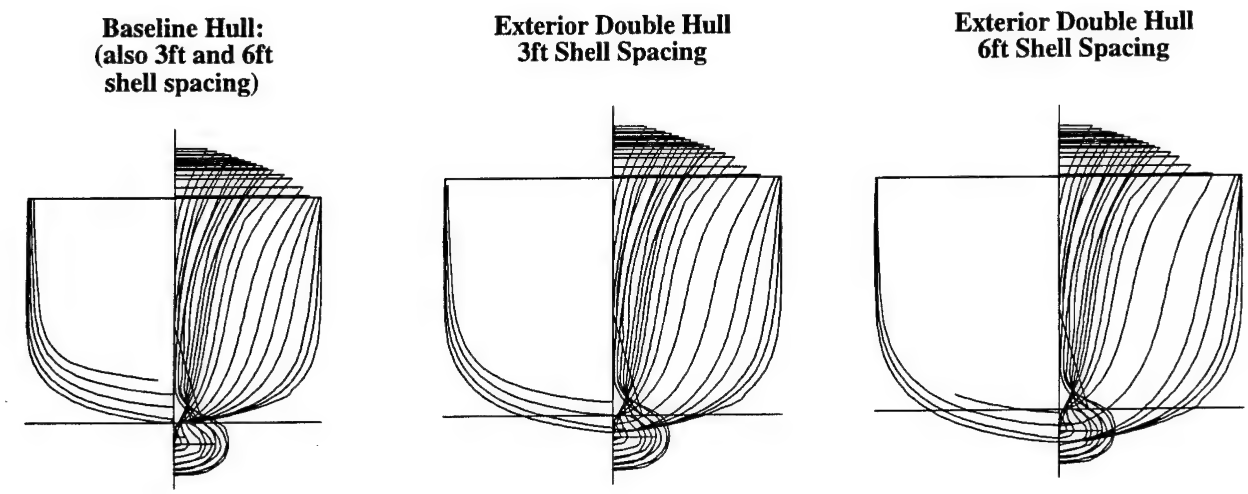


Figure 2. Body Plans of Original CG 47 and CG 47 Modified with External Double Hulls

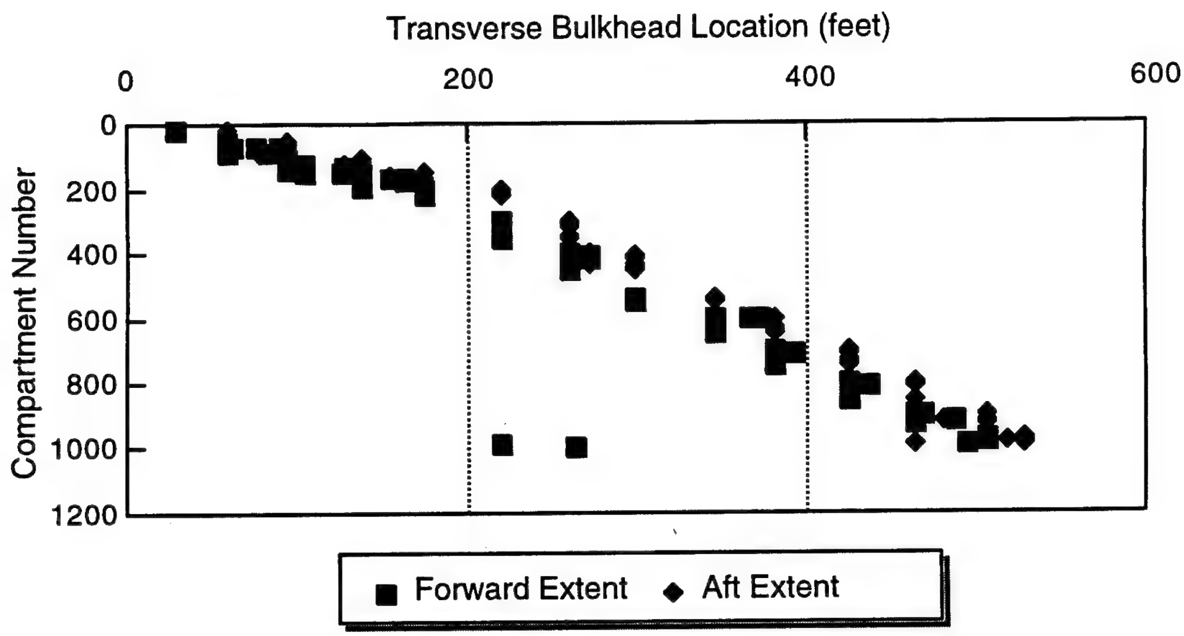


Figure 3. Fore and Aft Extents of Internal Compartmentation

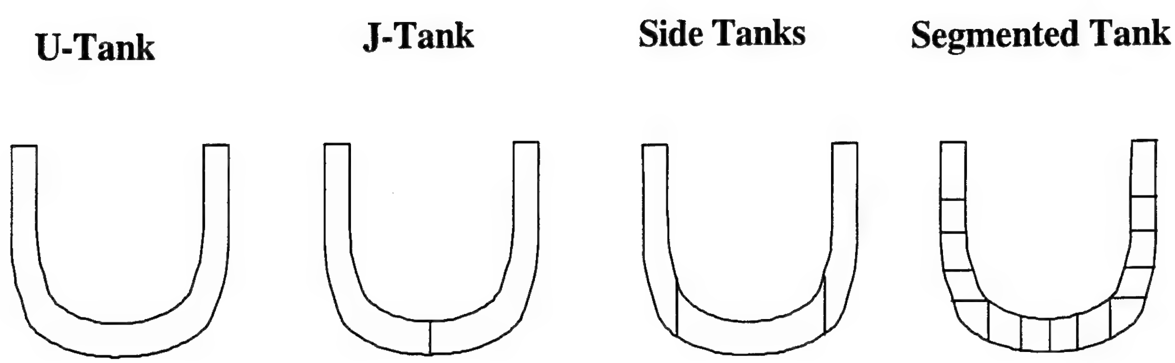


Figure 4. Double Hull Compartmentation Geometries

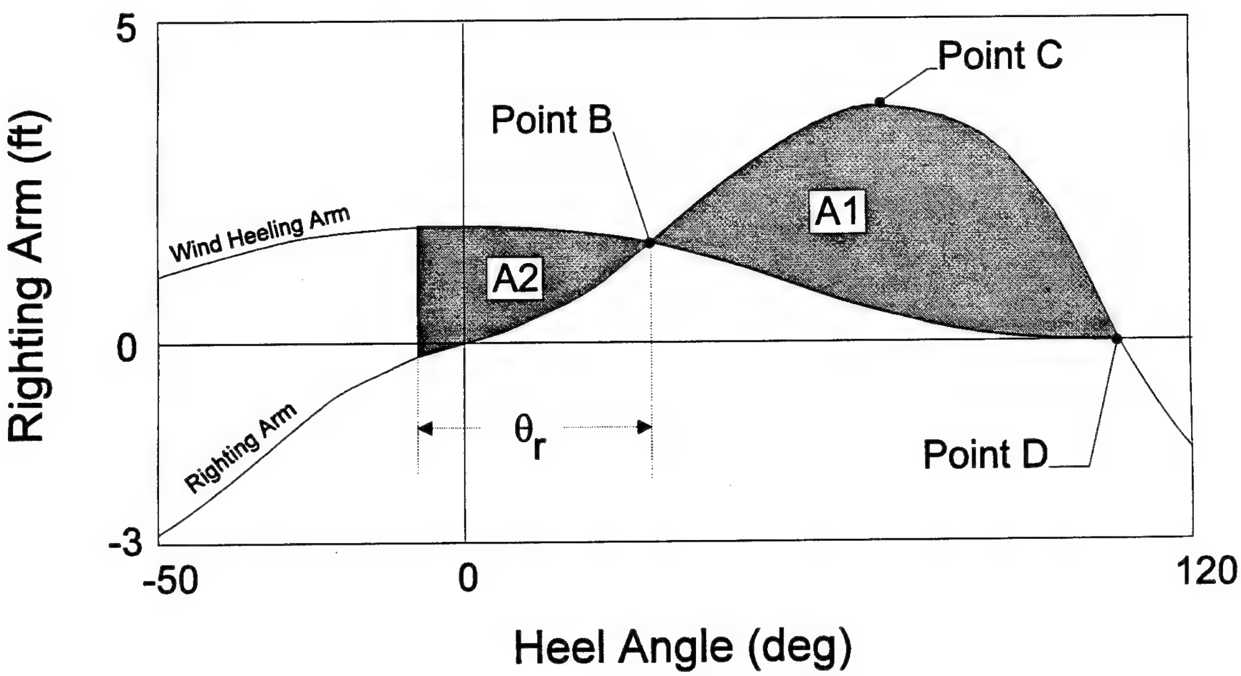


Figure 5. Sample Intact Righting Arm and Wind Heeling Arm Curves

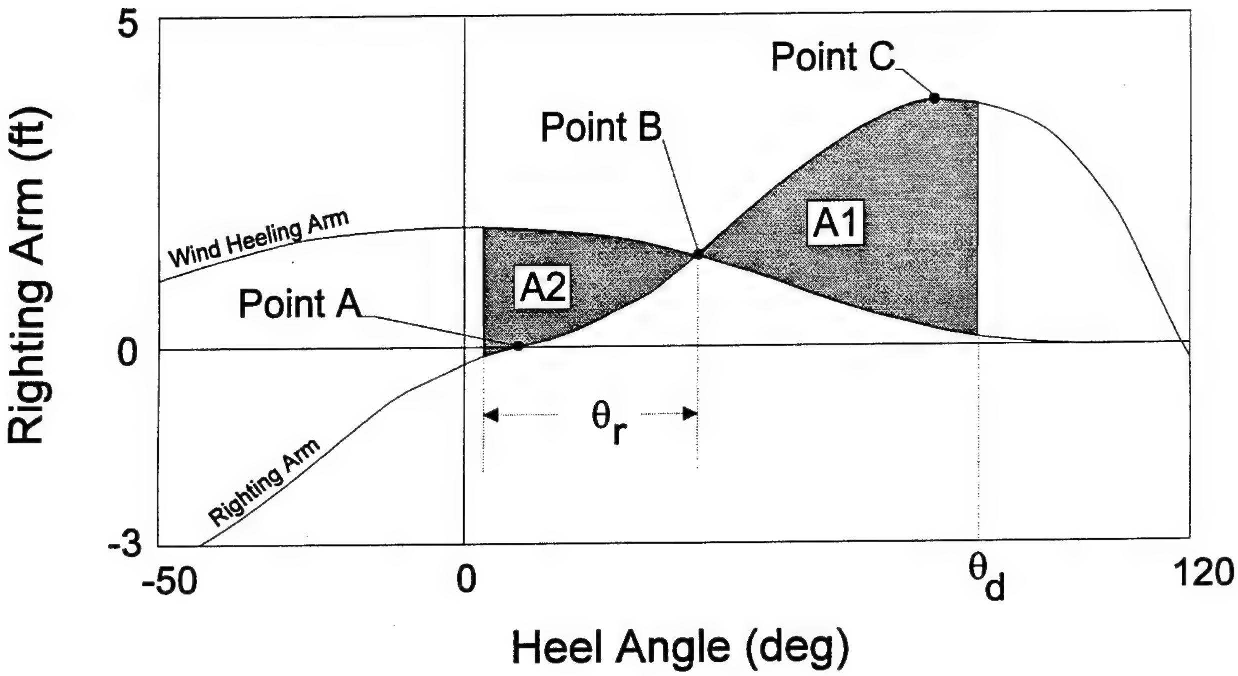


Figure 6. Sample Damaged Condition Righting Arm and Wind Heeling Arm Curves

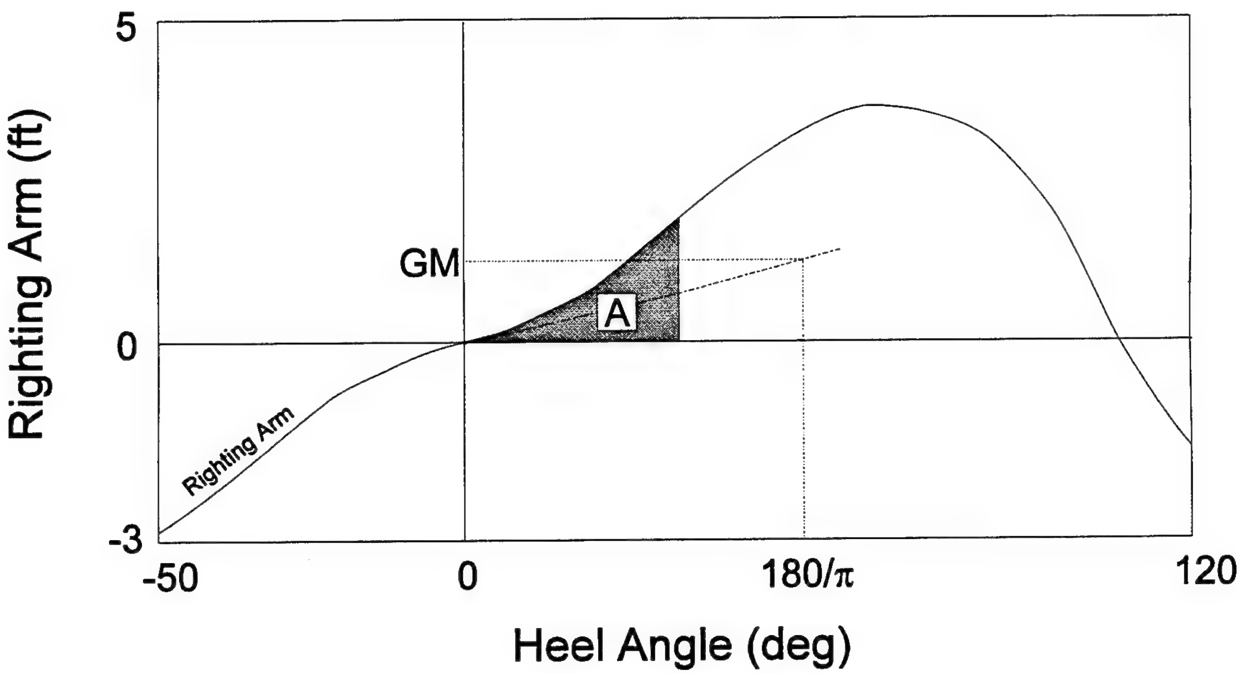


Figure 7. Sample Intact Righting Arm Curve

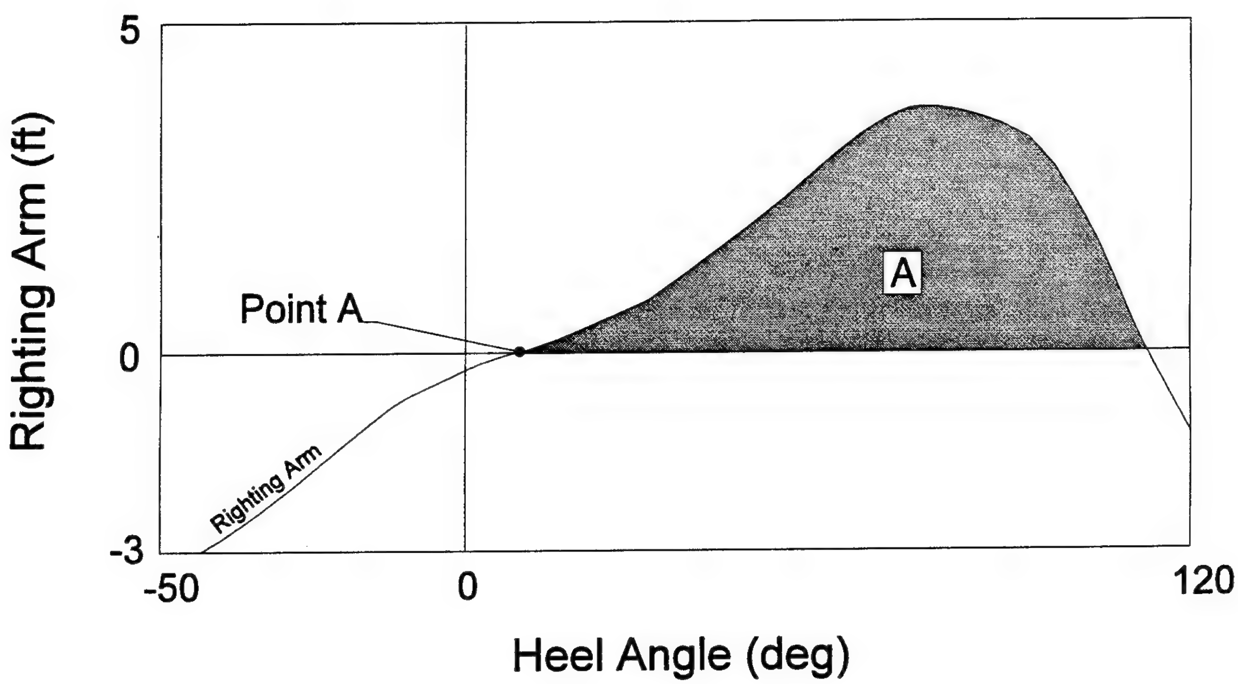


Figure 8. Sample Damaged Righting Arm Curve

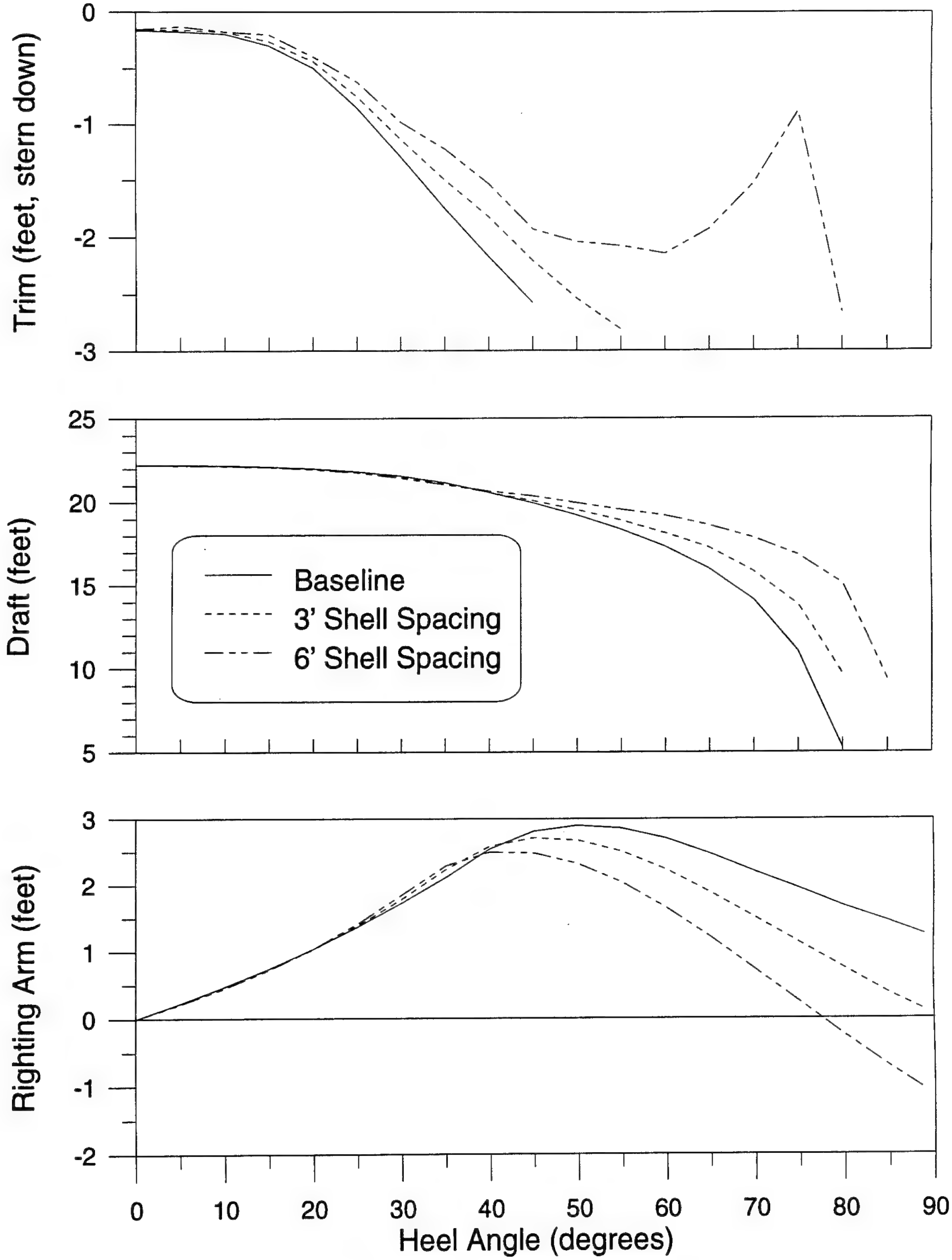


Figure 9. Intact Stability Characteristics

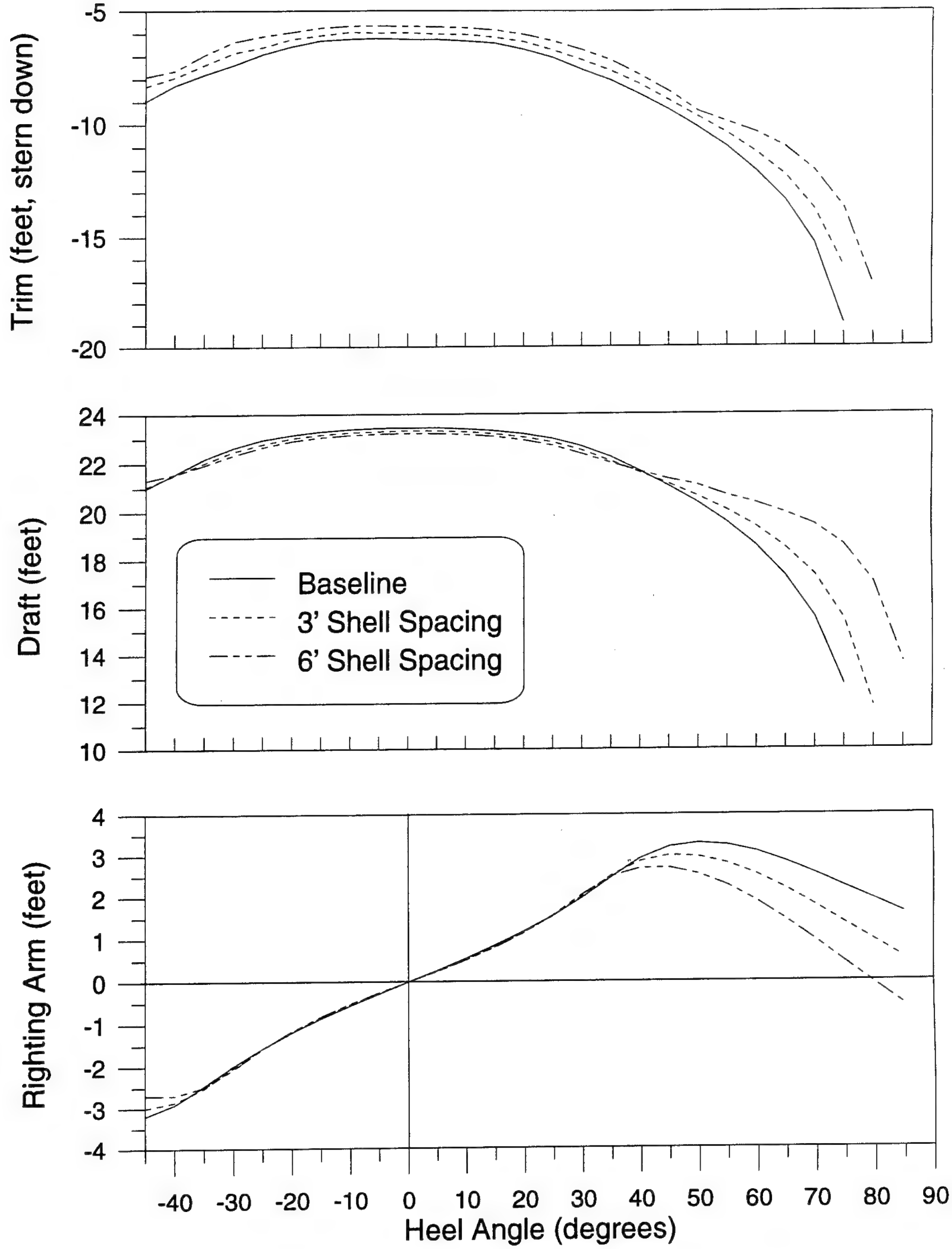


Figure 10. Damage Stability Characteristics - 15%L Damage, Station 0 to Station 3

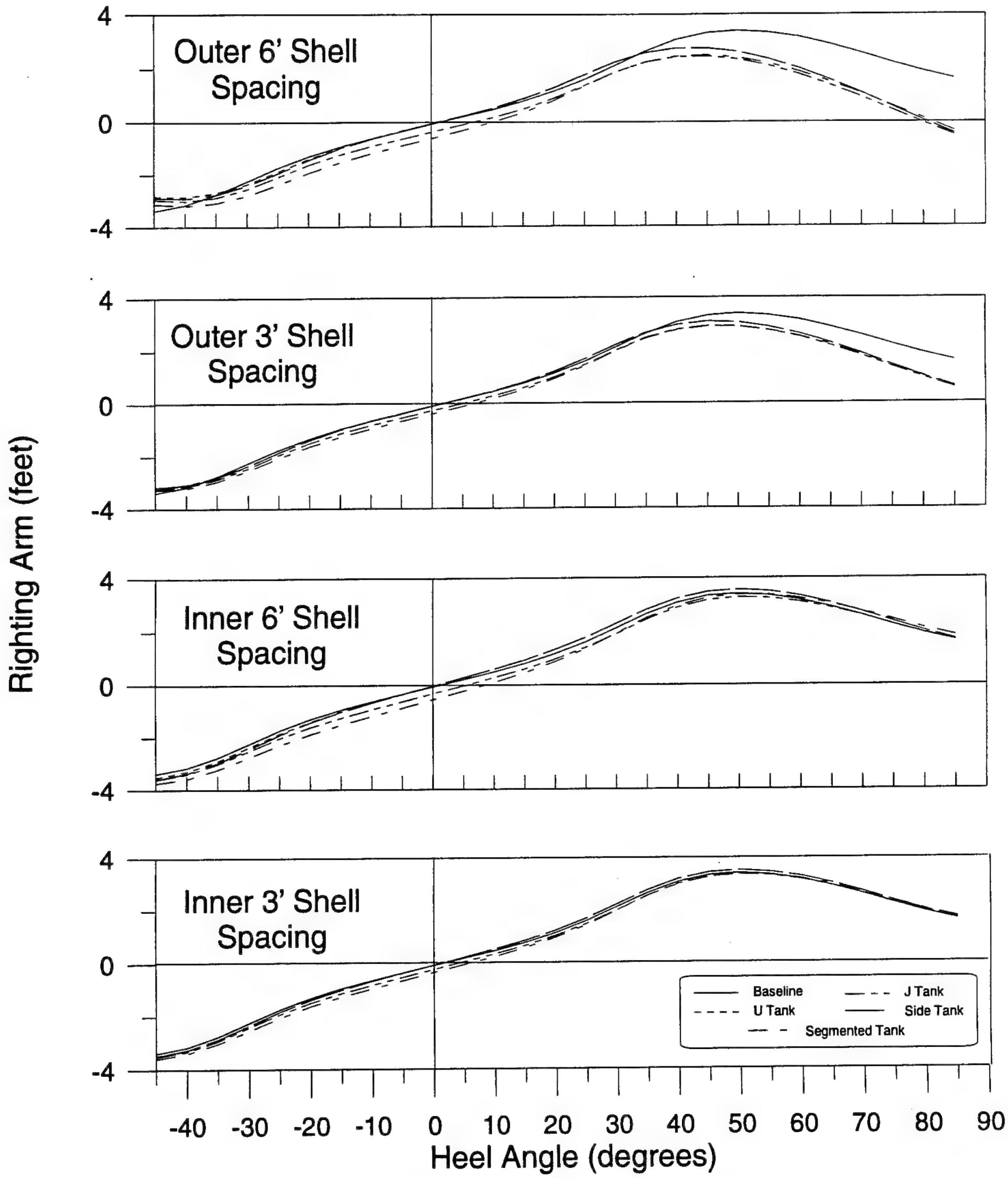


Figure 11. Damage Stability Characteristics by Double Hull Spacing - 15%L Damage, Station 3 to Station 6

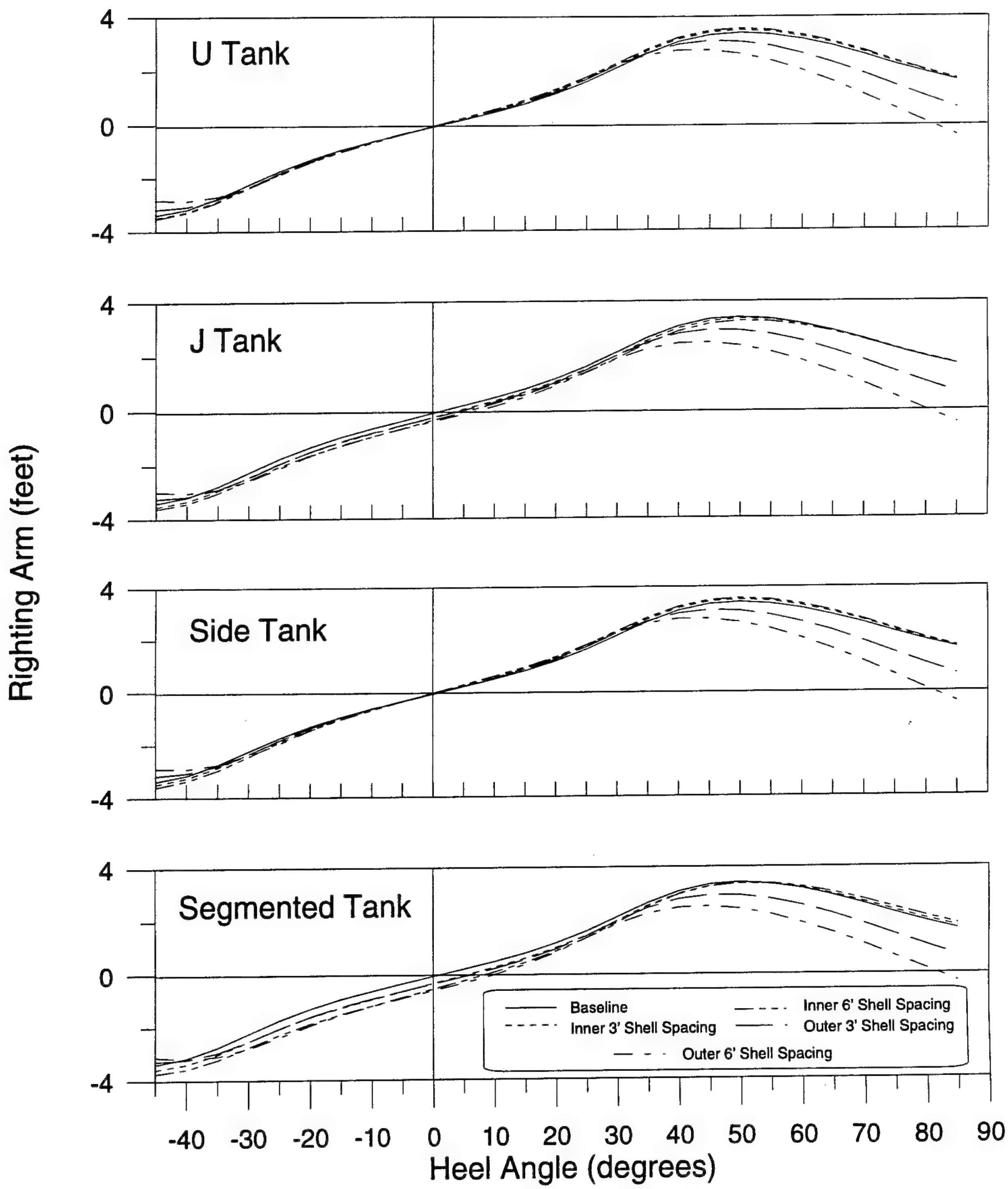


Figure 12. Damage Stability Characteristics by Double Hull Geometry - !5%L Damage, Station 3 to Station 6

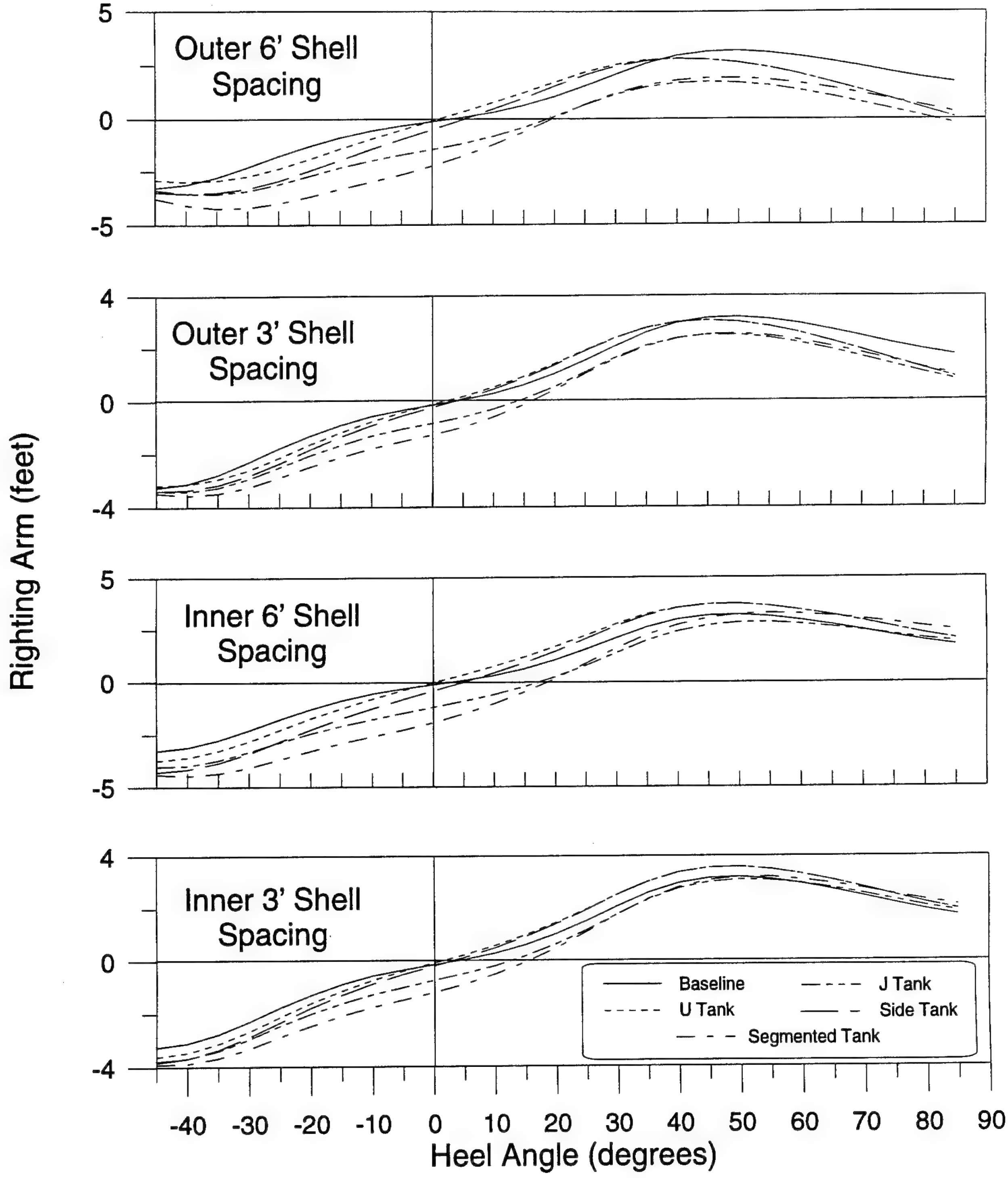


Figure 13. Damage Stability Characteristics by Double Hull Spacing - 15%L Damage, Station 6 to Station 9

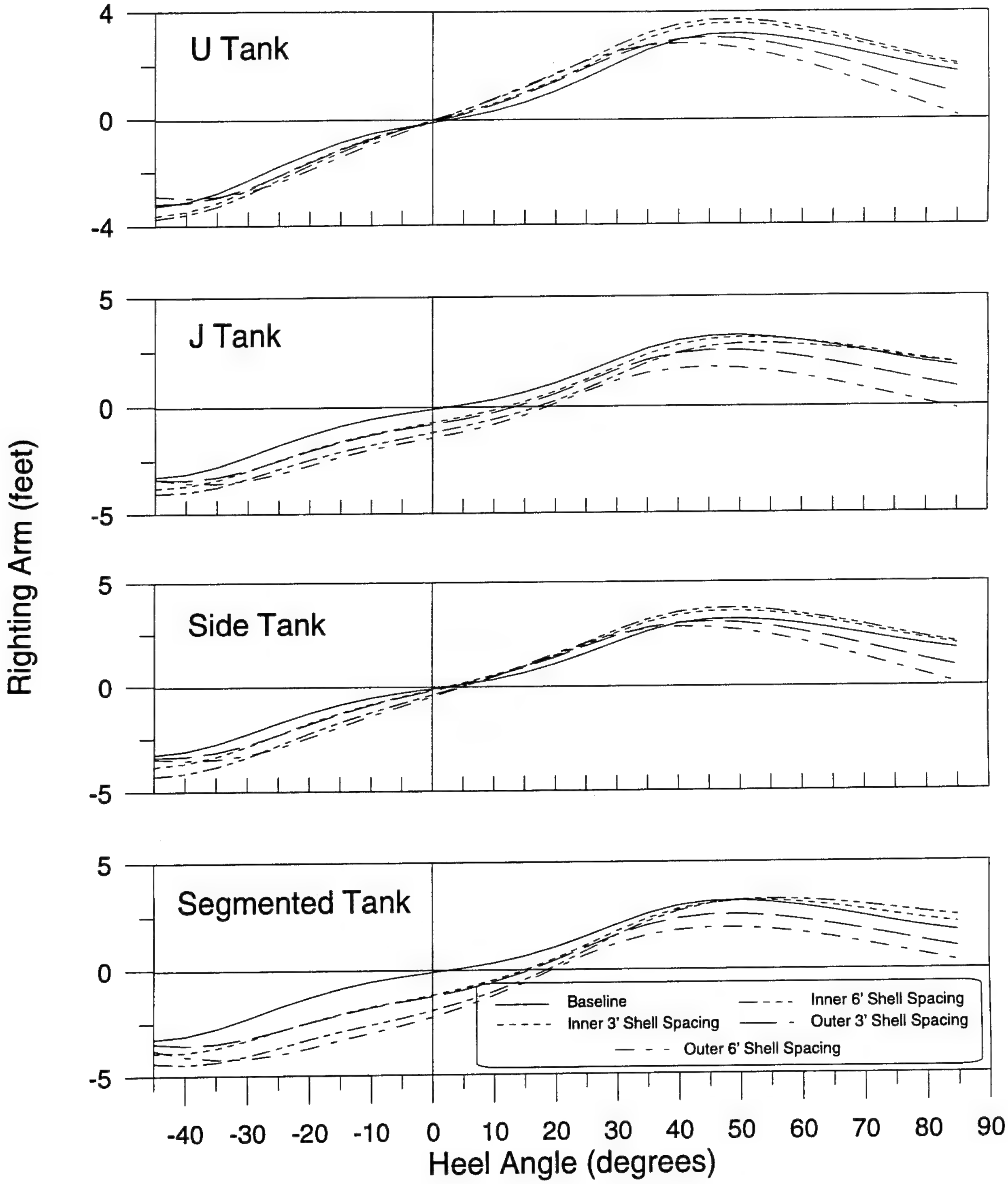


Figure 14. Damage Stability Characteristics by Double Hull Geometry - 15%L Damage, Station 6 to Station 9

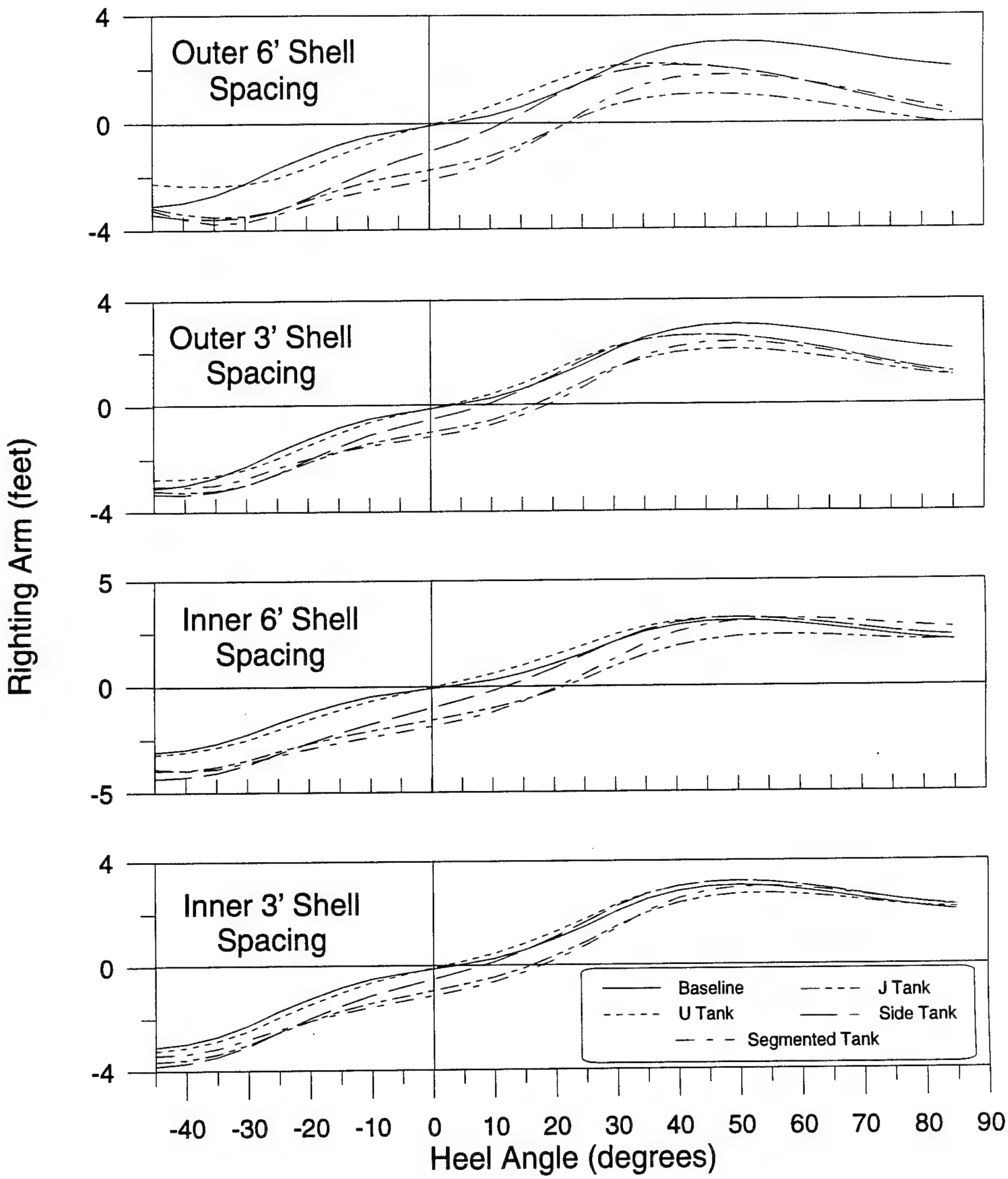


Figure 15. Damage Stability Characteristics by Double Hull Spacing - 15%L Damage, Station 9 to Station 12

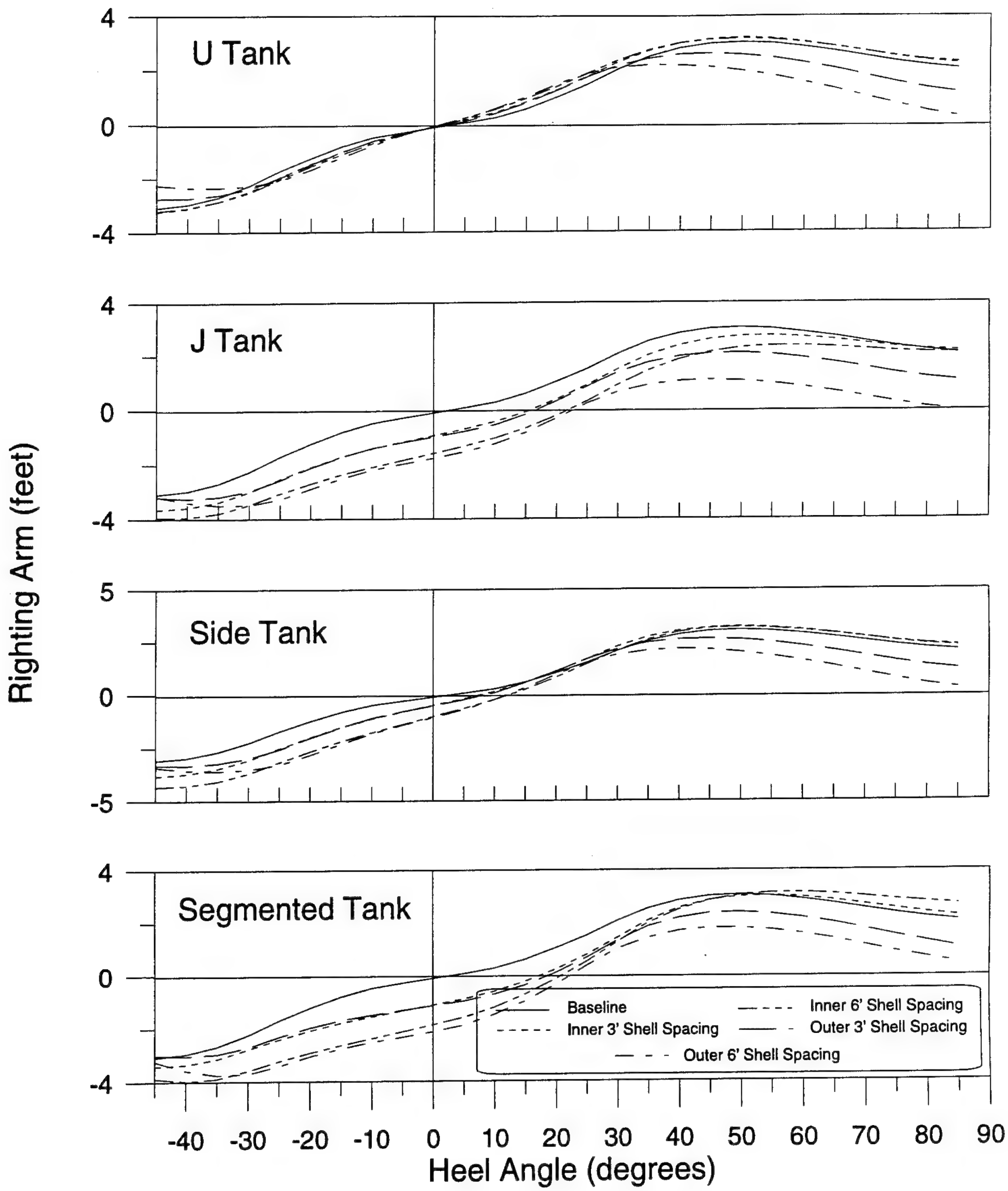


Figure 16. Damage Stability Characteristics by Double Hull Geometry - 15%L Damage, Station 9 to Station 12

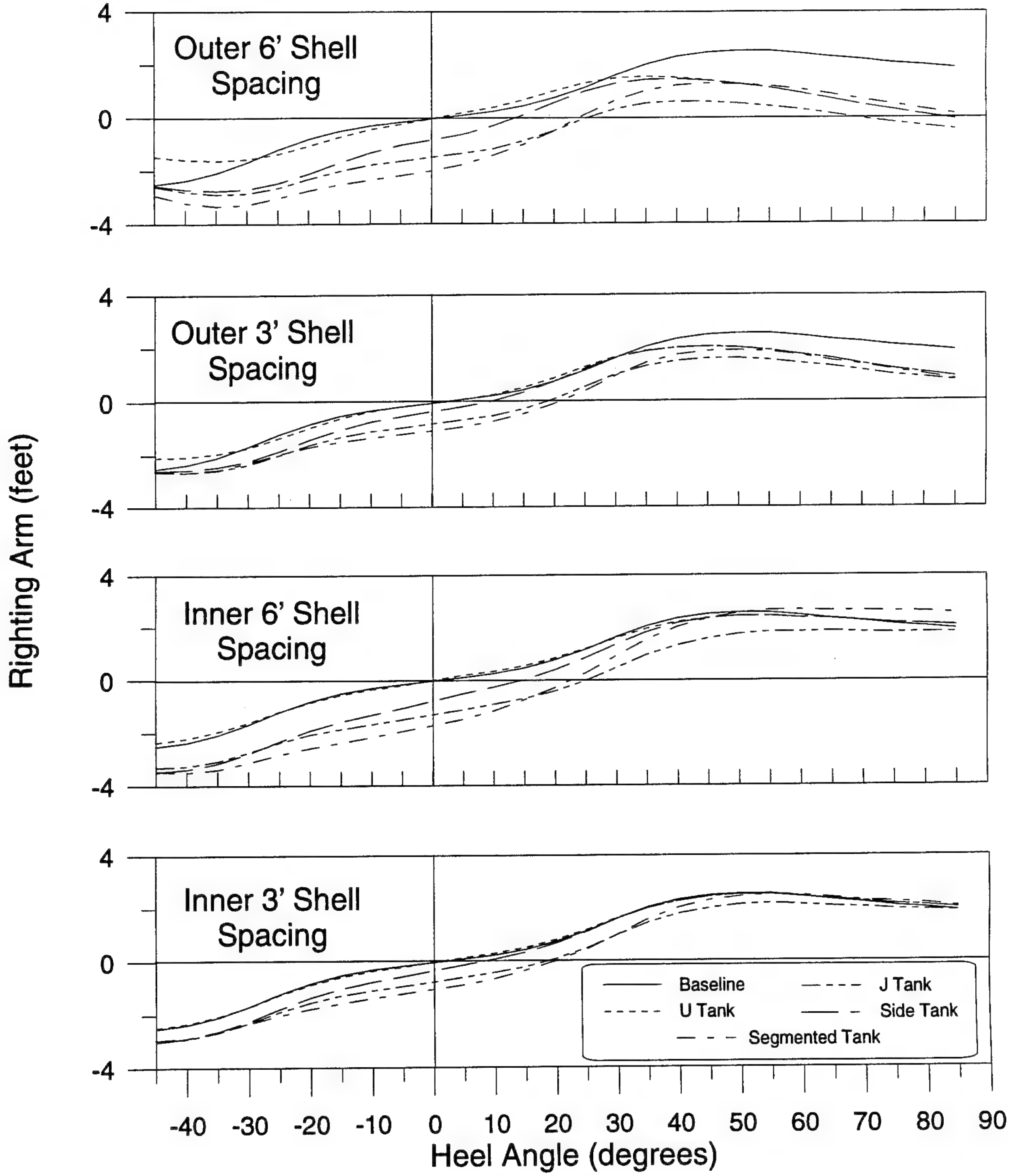


Figure 17. Damage Stability Characteristics by Double Hull Spacing - 15%L Damage, Station 12 to Station 15

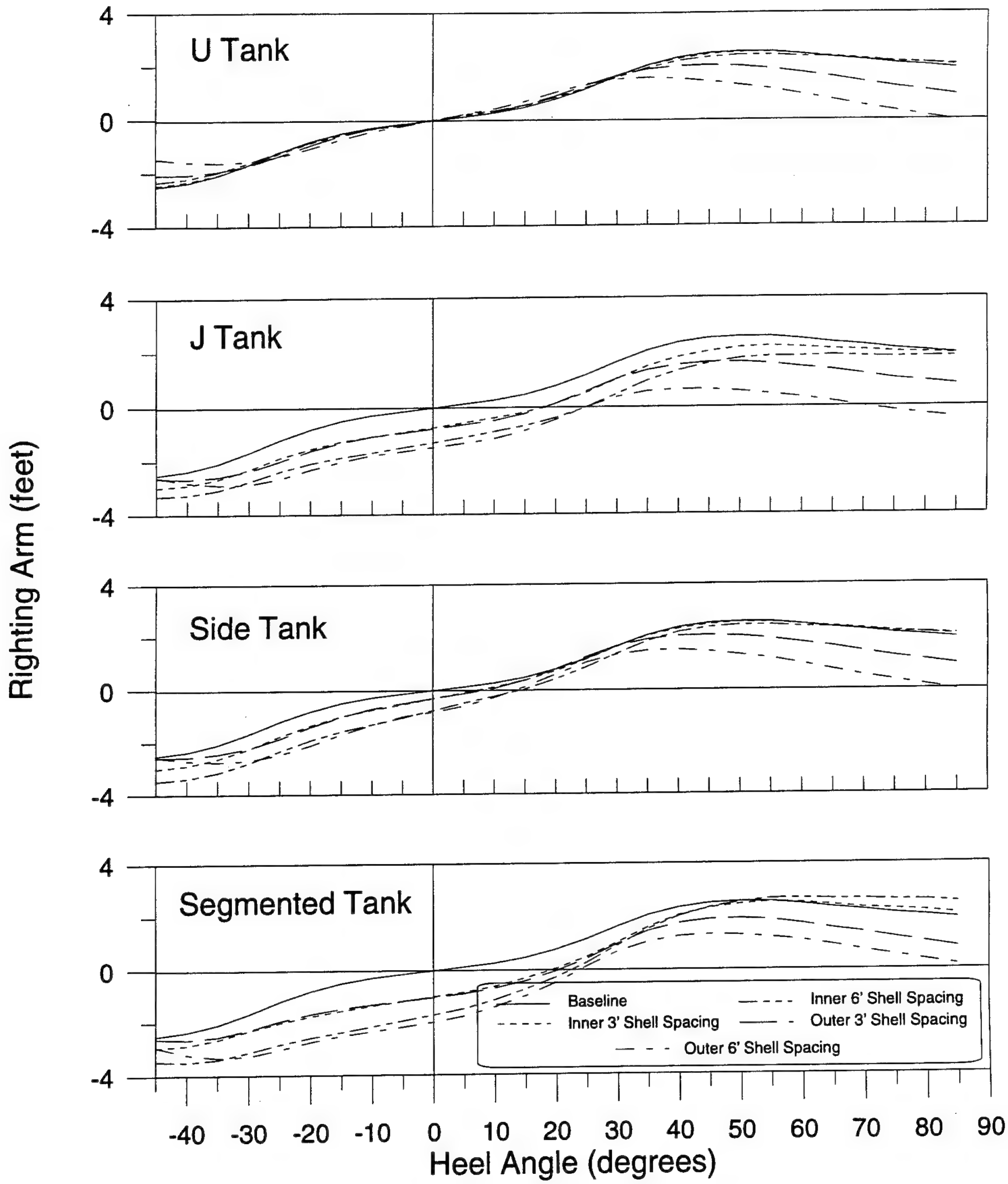


Figure 18. Damage Stability Characteristics by Double Hull Geometry - 15%L Damage, Station 12 to Station 15

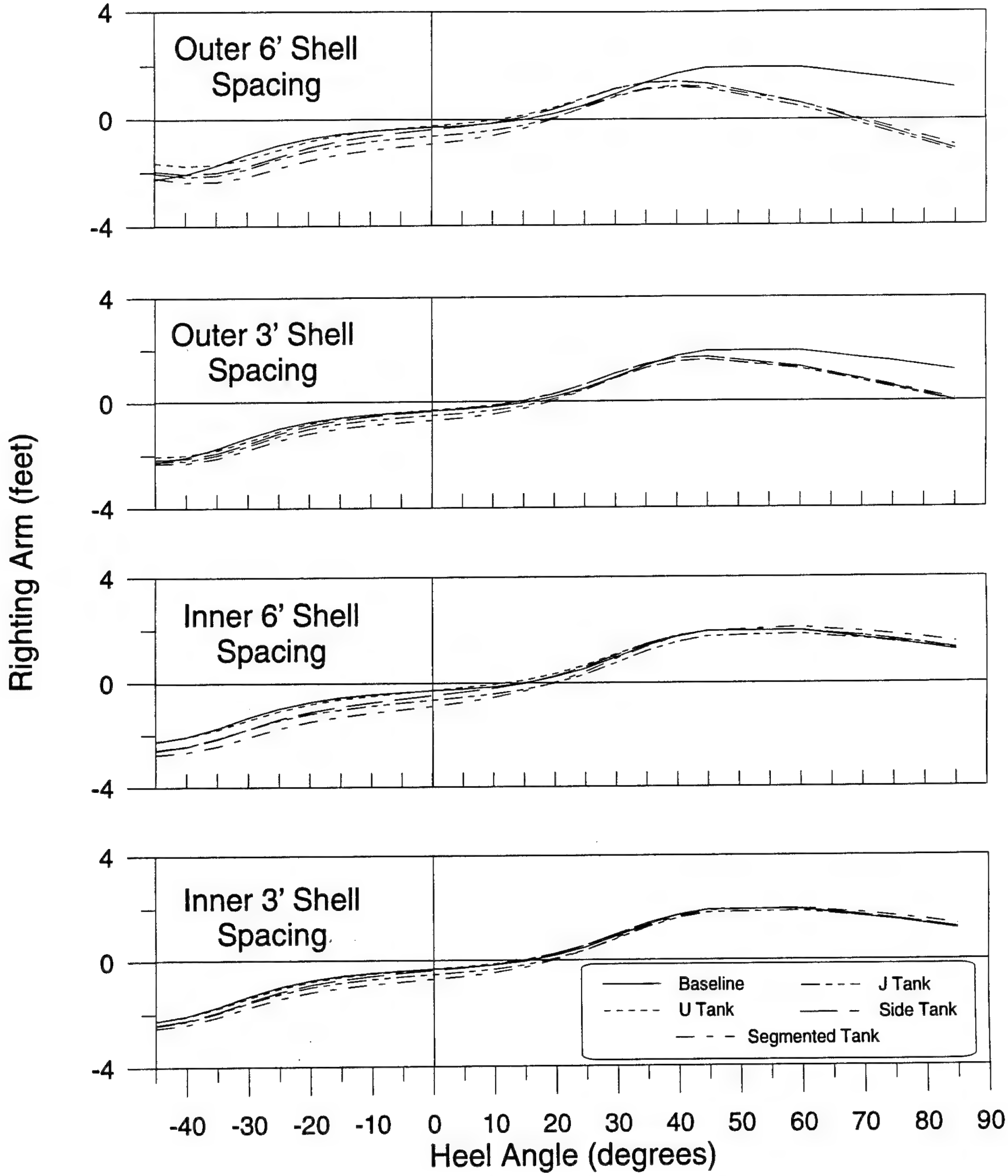


Figure 19. Damage Stability Characteristics by Double Hull Spacing - 15%L Damage, Station 15 to Station 18

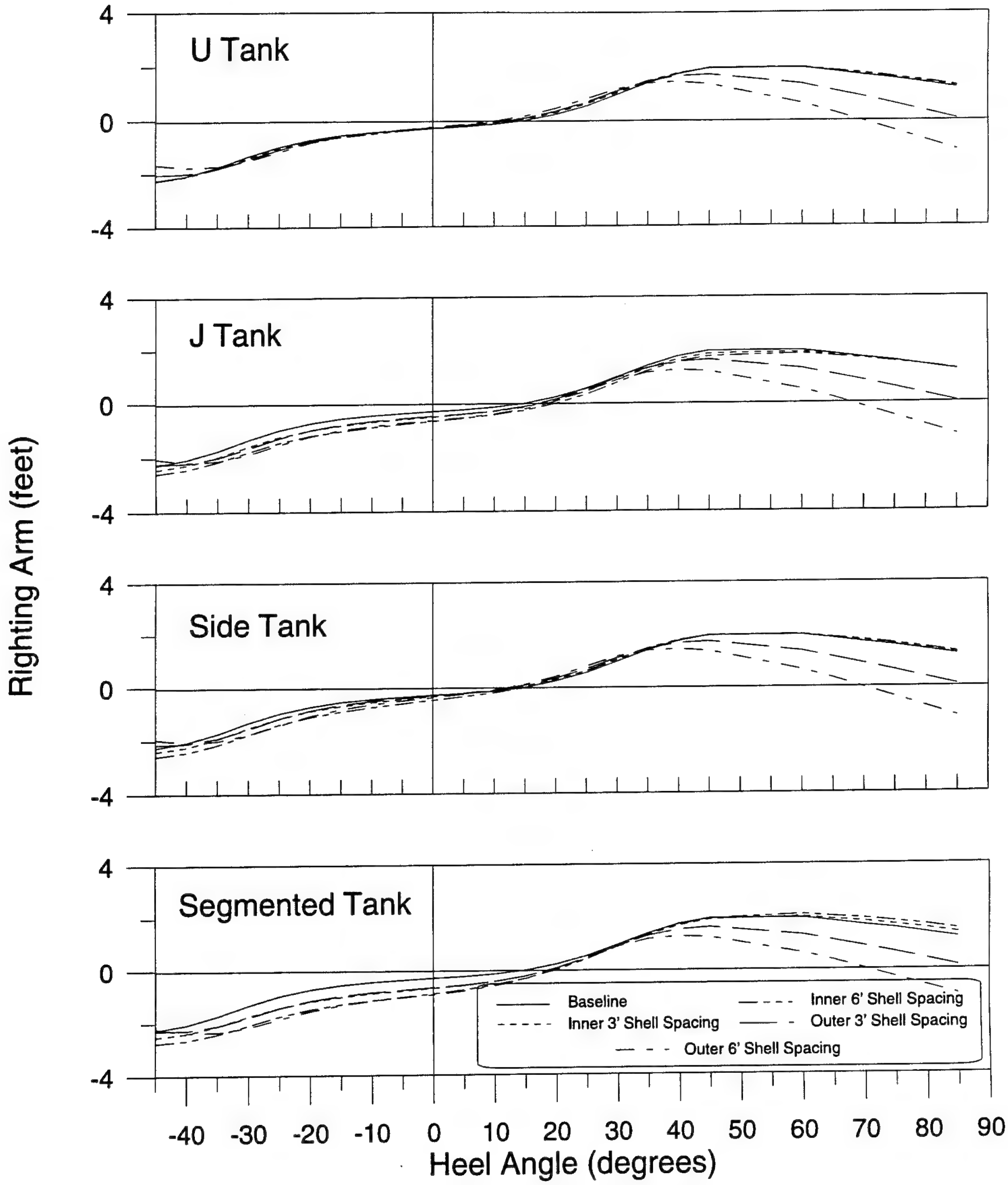


Figure 20. Damage Stability Characteristics by Double Hull Geometry - 15%L Damage, Station 15 to Station 18

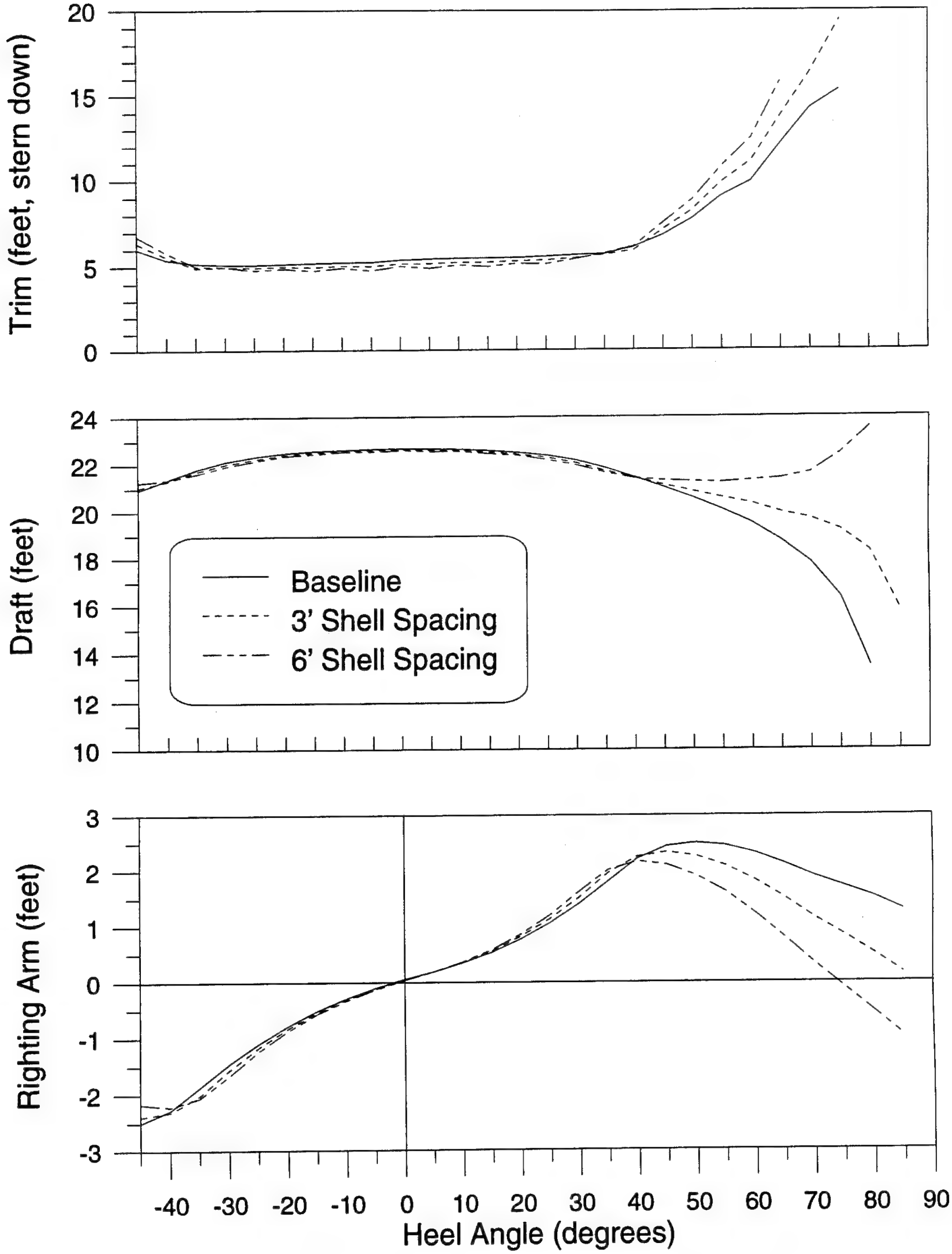


Figure 21. Damage Stability Characteristics - 15%L Damage, Station 18 to Station 20

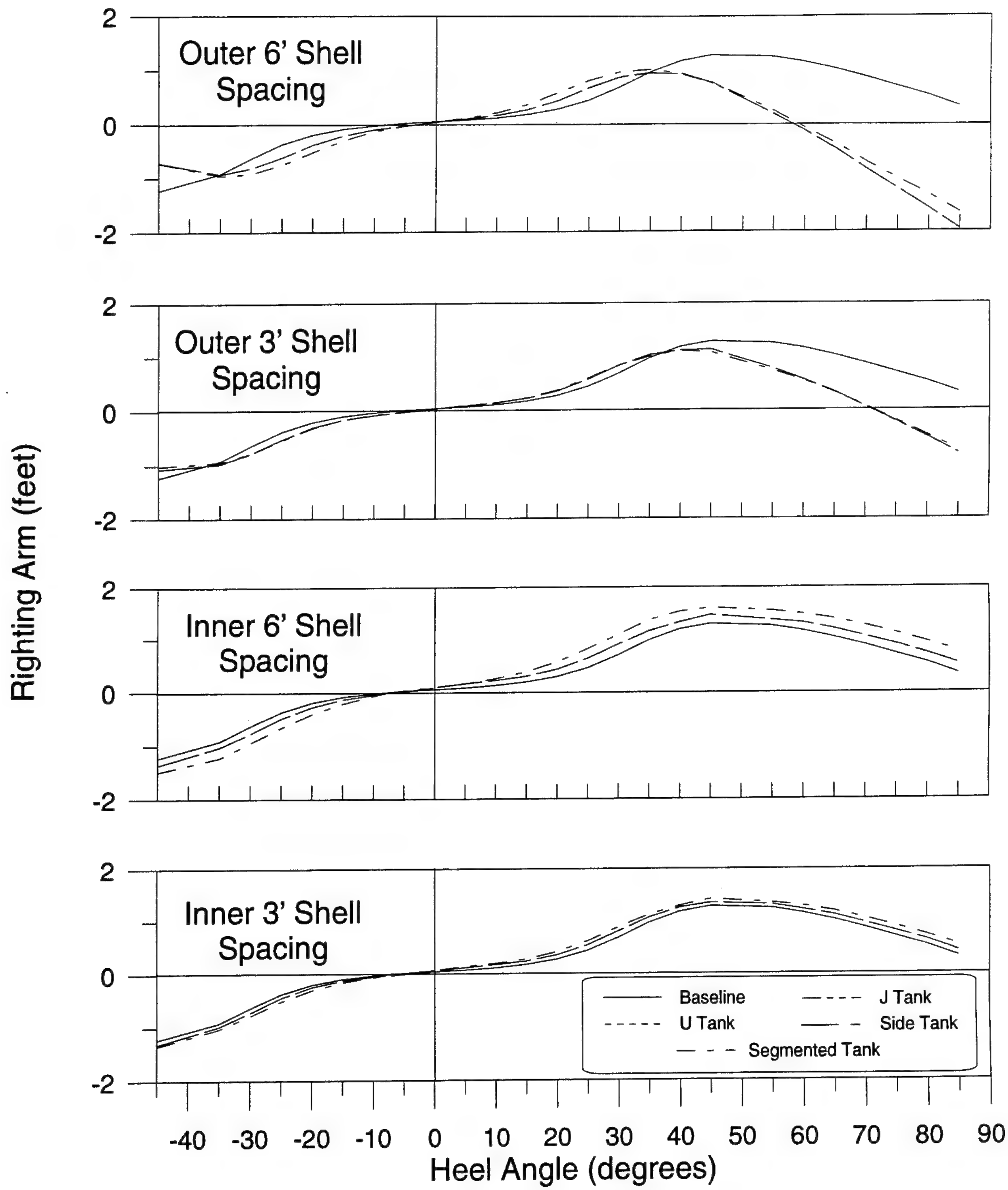


Figure 22. Damage Stability Characteristics by Double Hull Spacing - Symmetric Weapons Damage

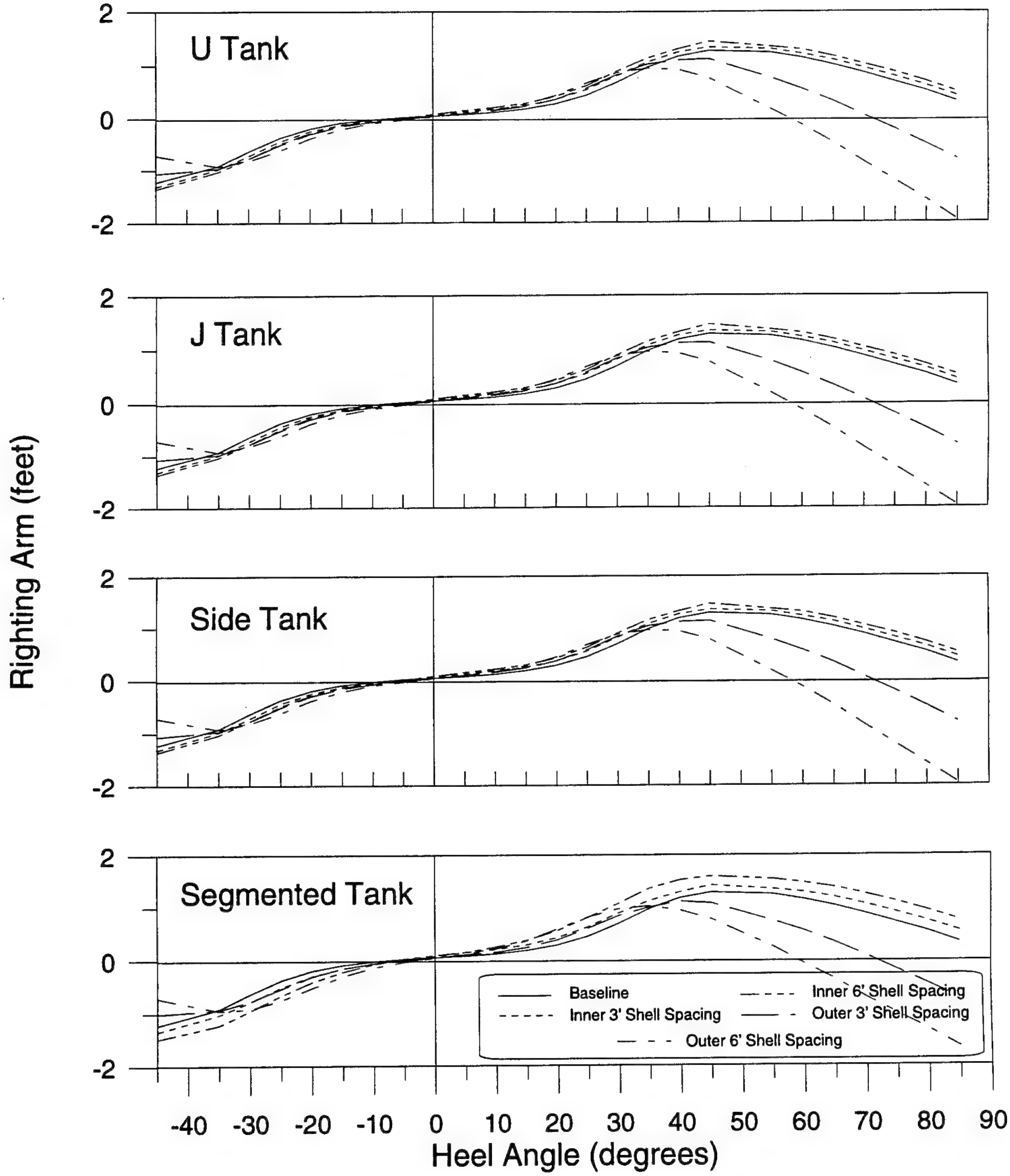


Figure 23. Damage Stability Characteristics by Double Hull Geometry - Symmetric Weapons Damage

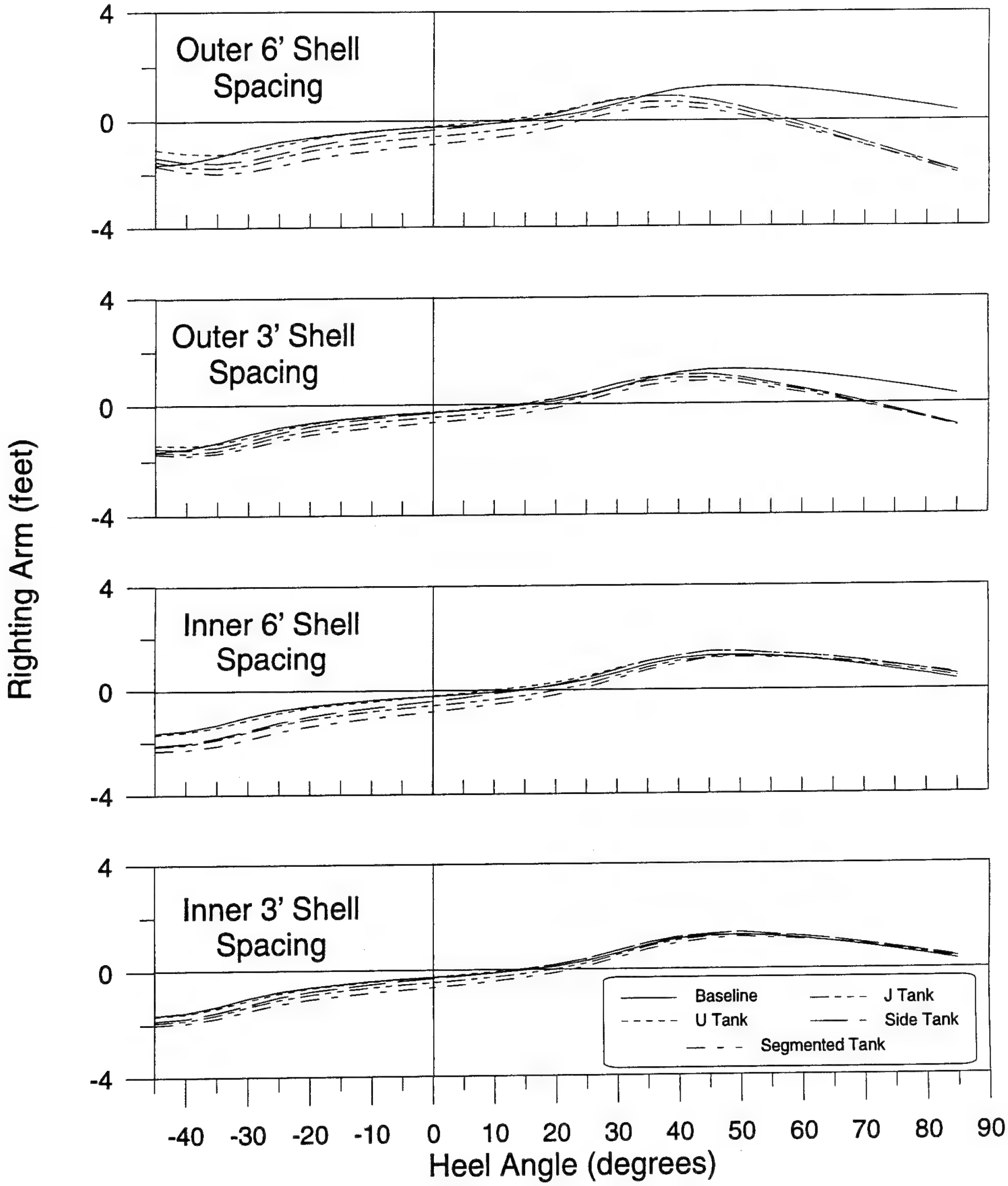


Figure 24. Damage Stability Characteristics by Double Hull Spacing - Asymmetric Weapons Damage

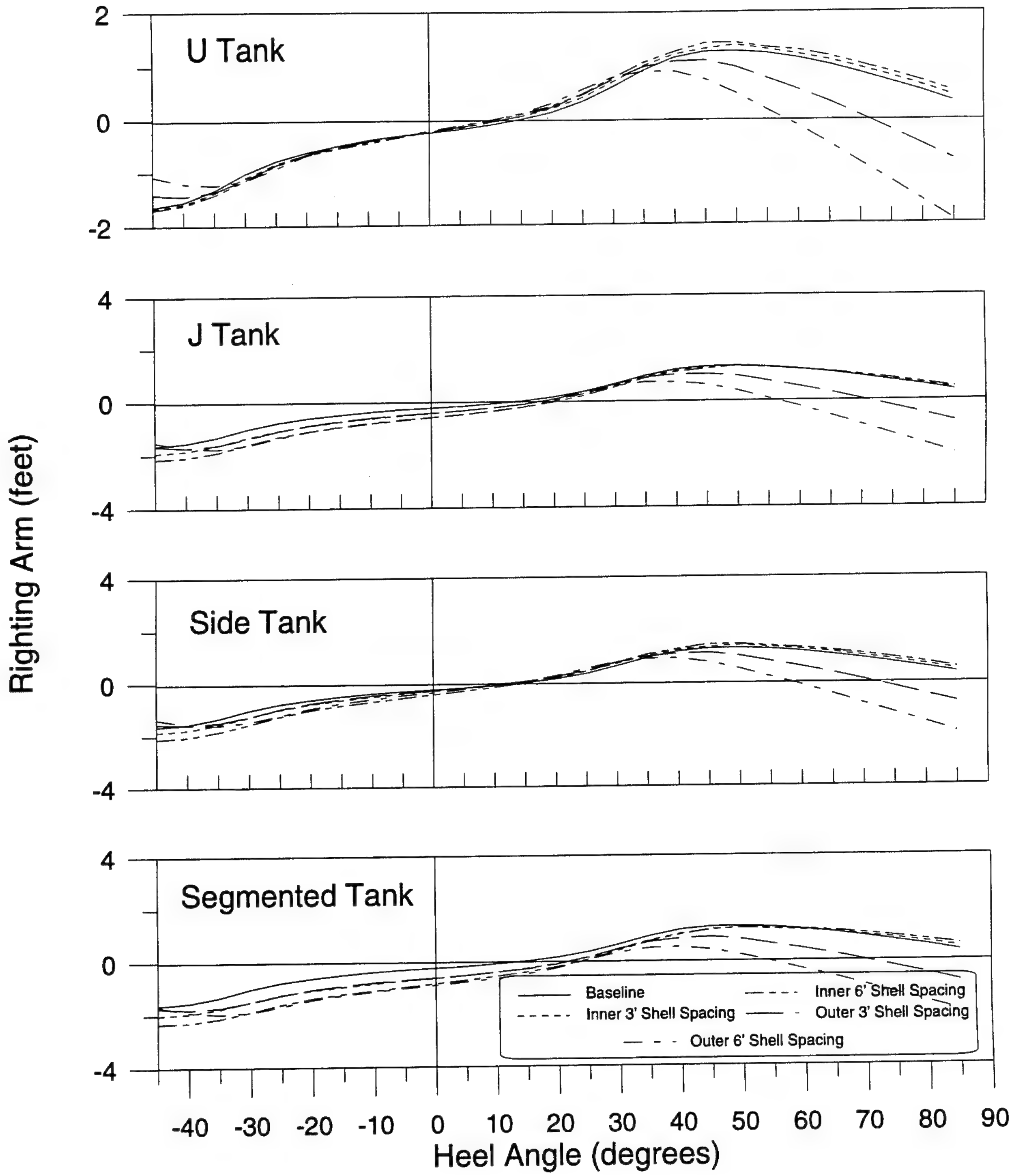


Figure 25. Damage Stability Characteristics by Double Hull Geometry - Asymmetric Weapons Damage

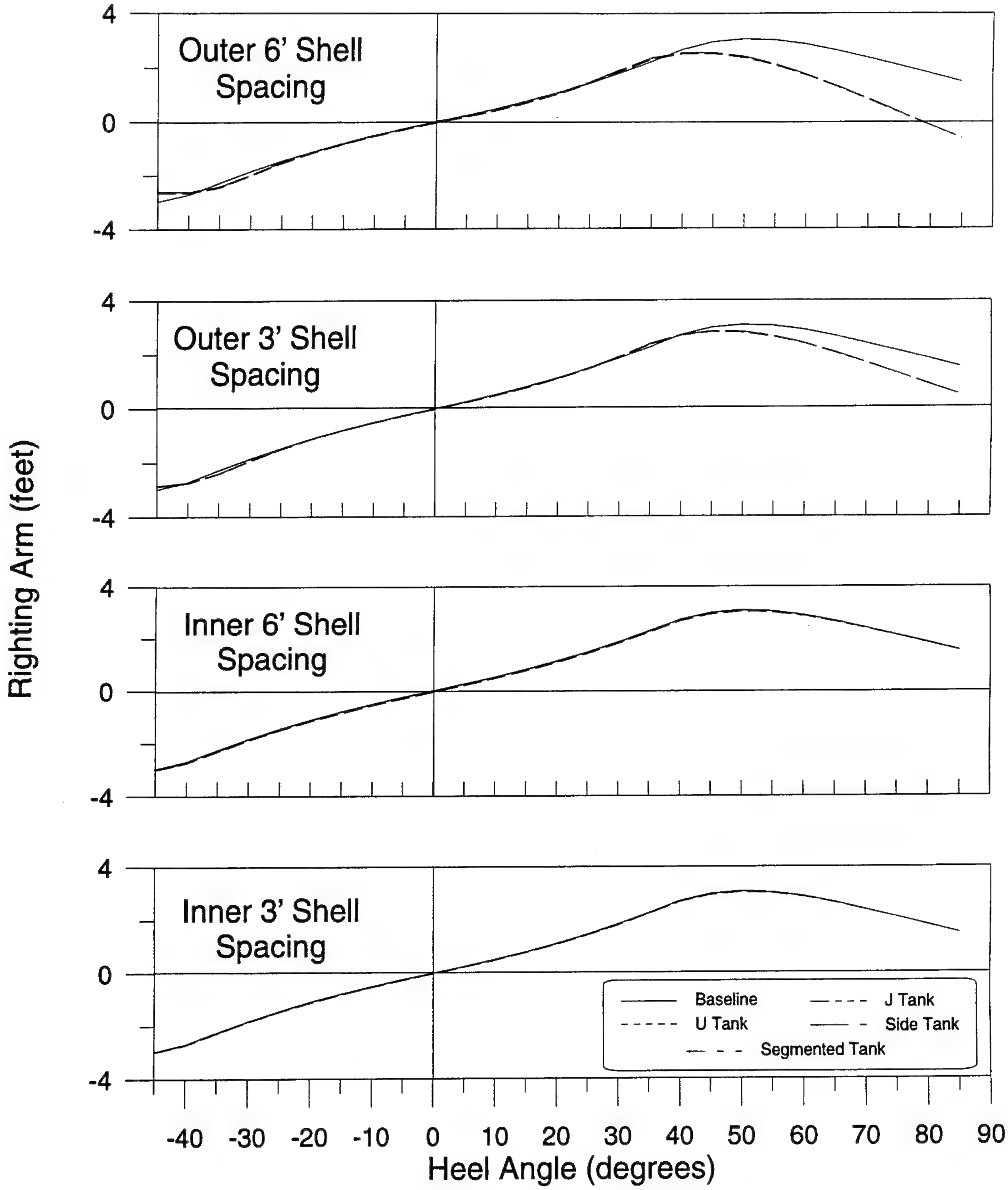


Figure 26. Damage Stability Characteristics by Double Hull Spacing - 20% Bottom Raking Damage

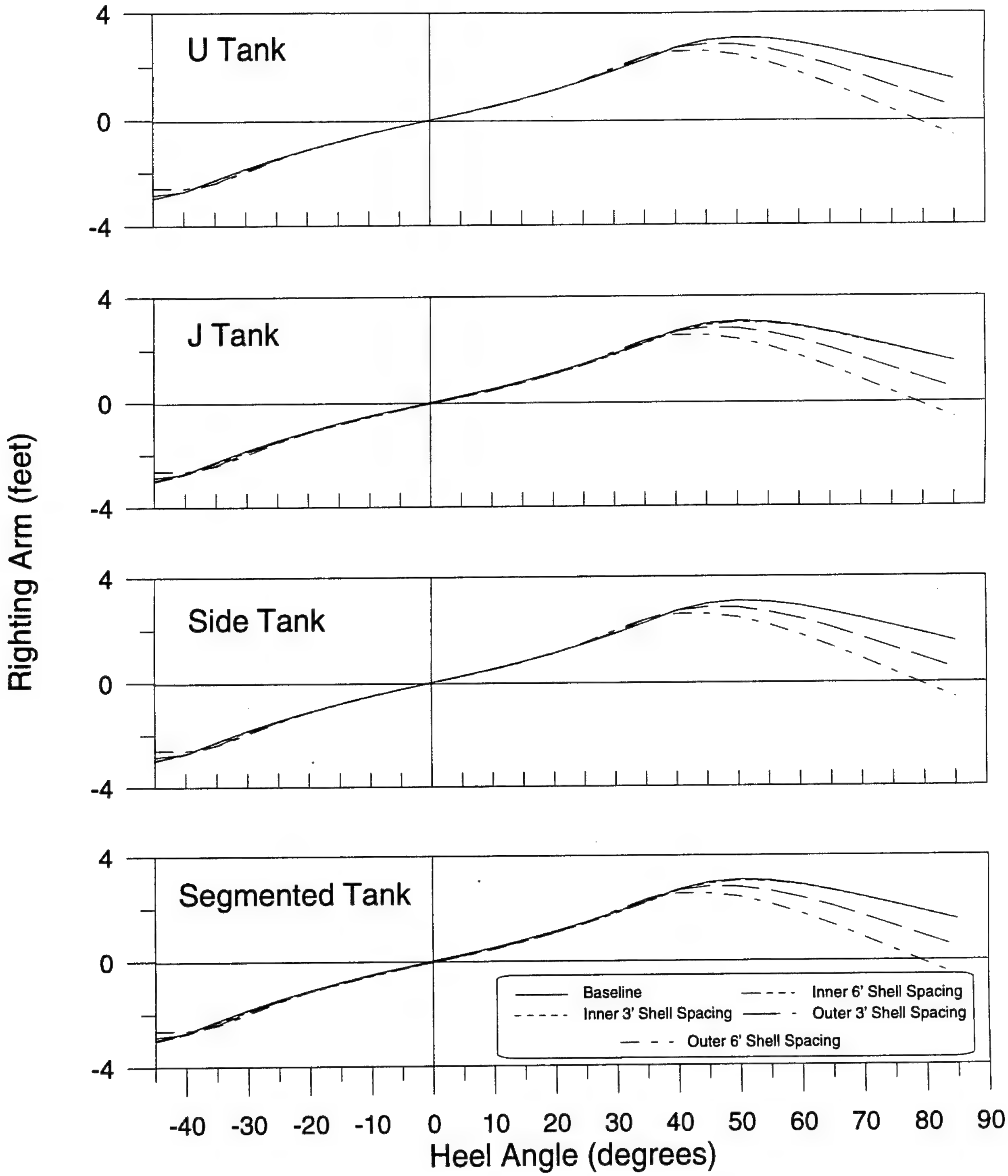


Figure 27. Damage Stability Characteristics by Double Hull Spacing - 20% Bottom Raking Damage

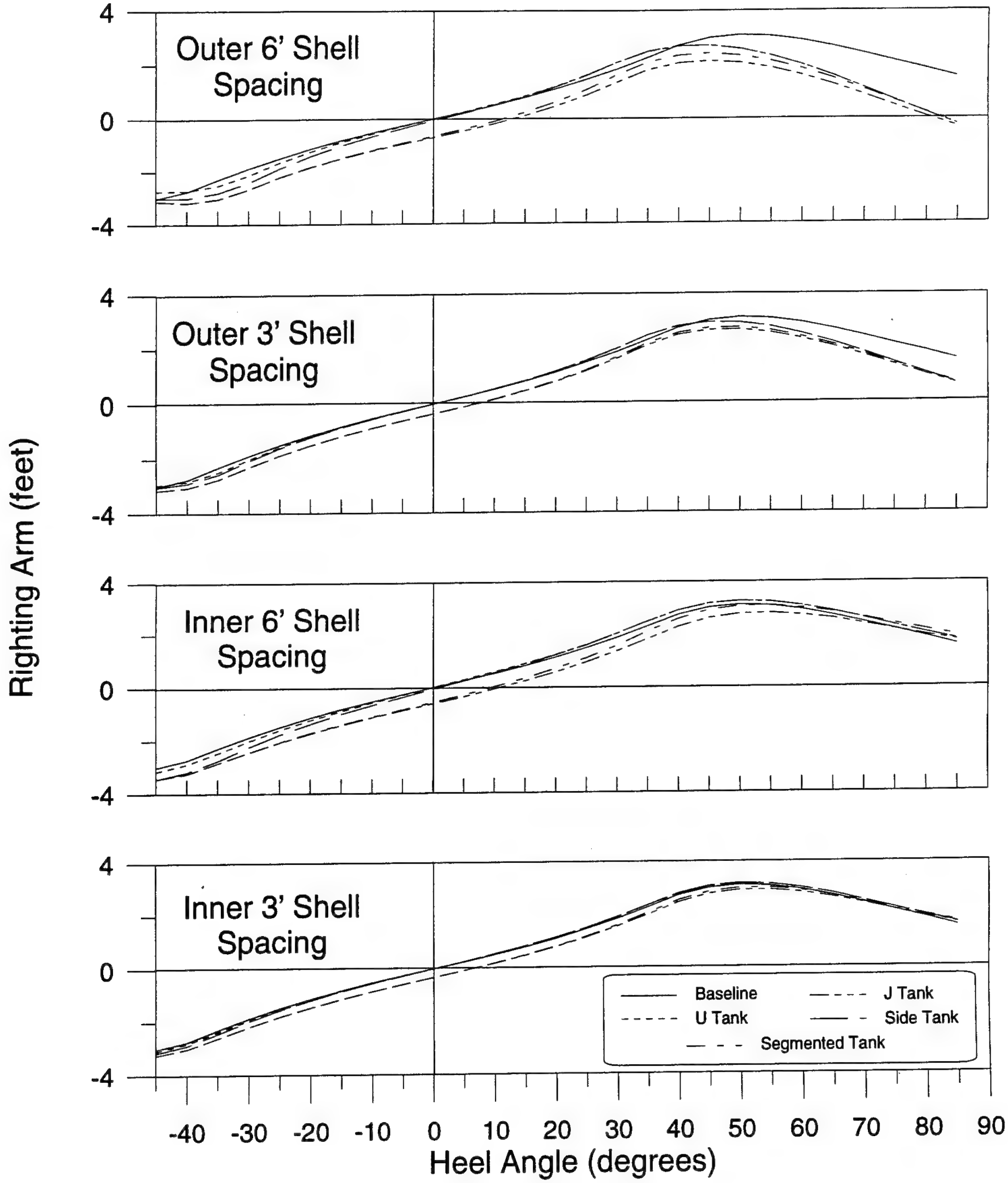


Figure 28. Damage Stability Characteristics by Double Hull Geometry - 40% Bottom Raking Damage

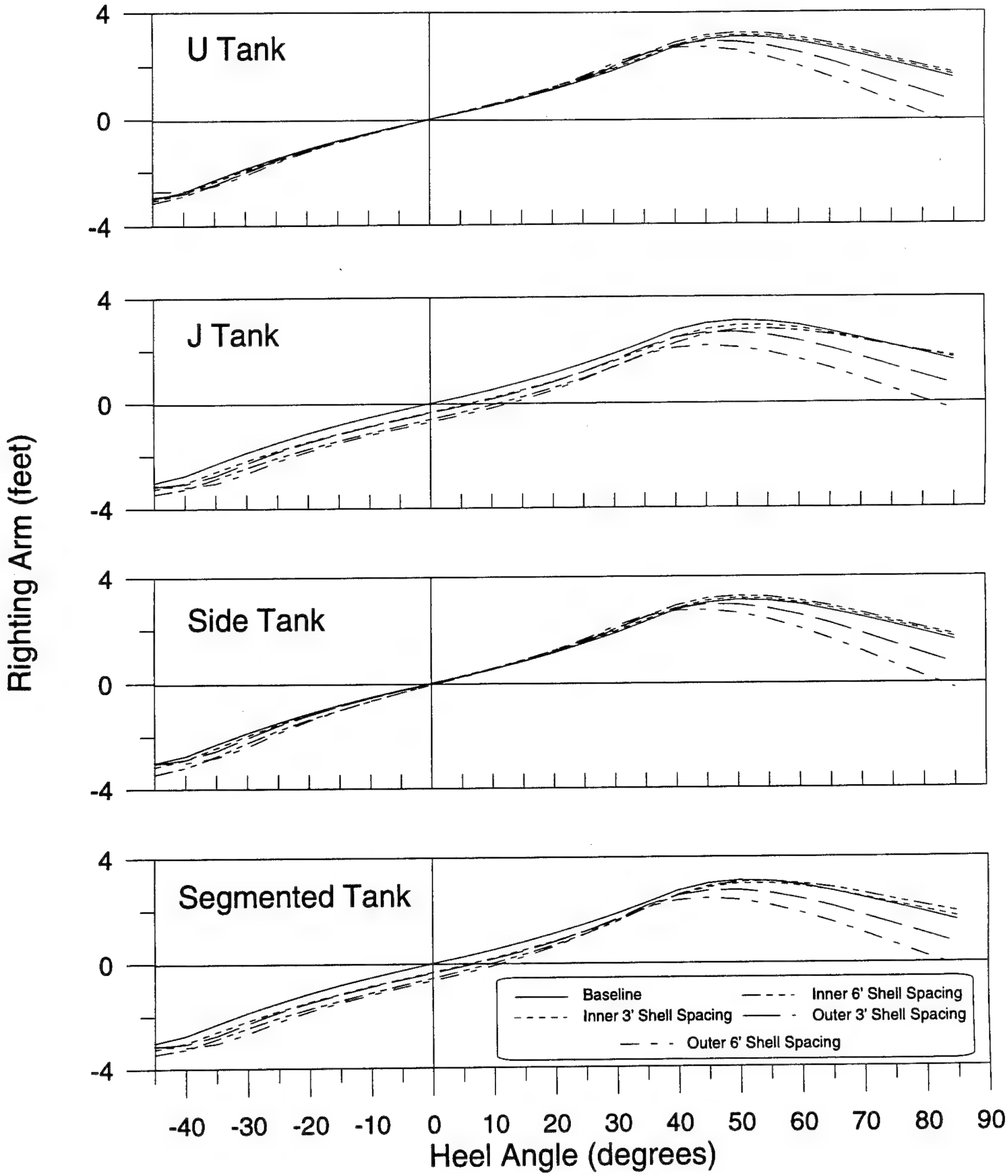


Figure 29. Damage Stability Characteristics by Double Hull Geometry - 40% Bottom Raking Damage

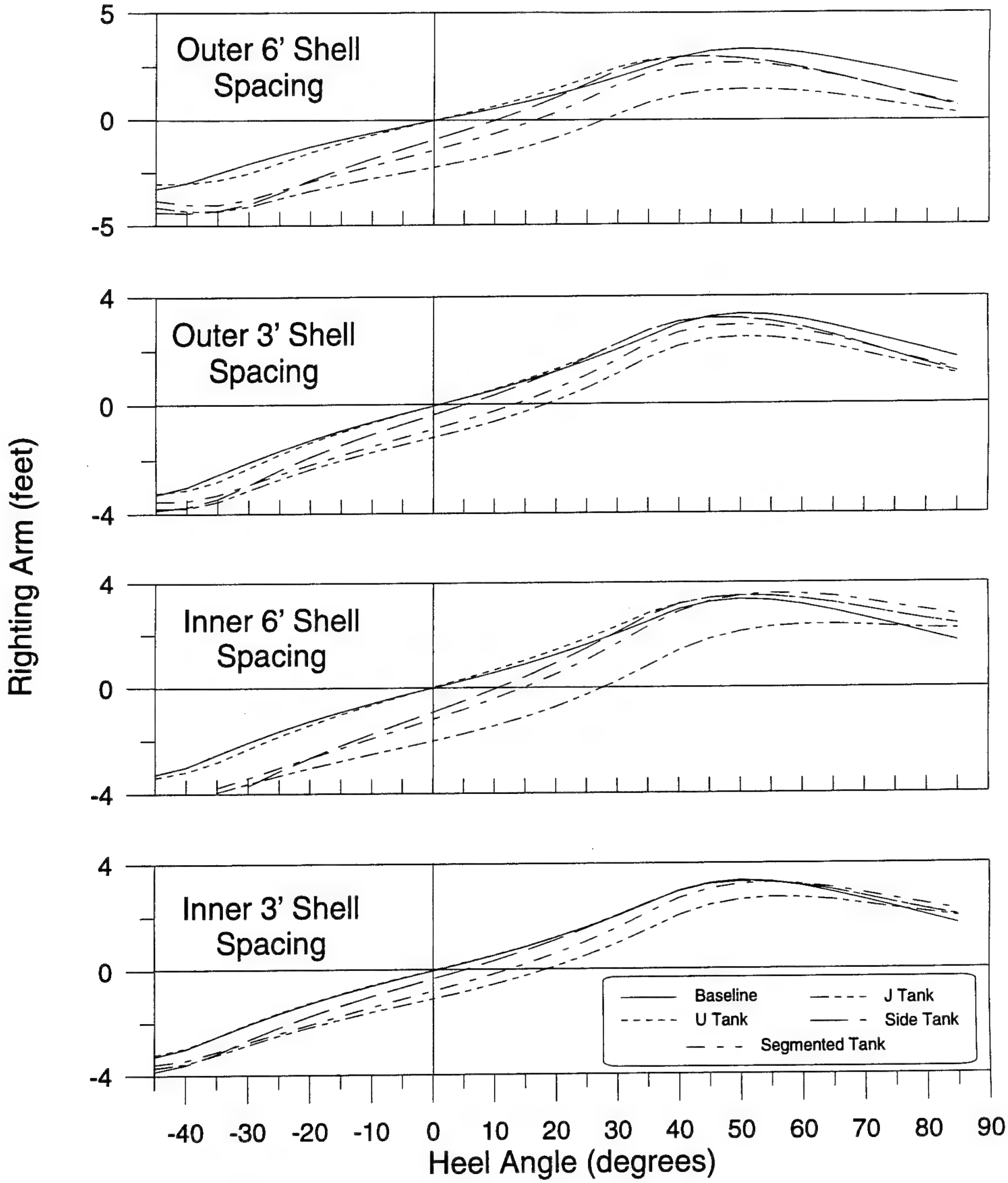


Figure 30. Damage Stability Characteristics by Double Hull Spacing - 60% Bottom Raking Damage

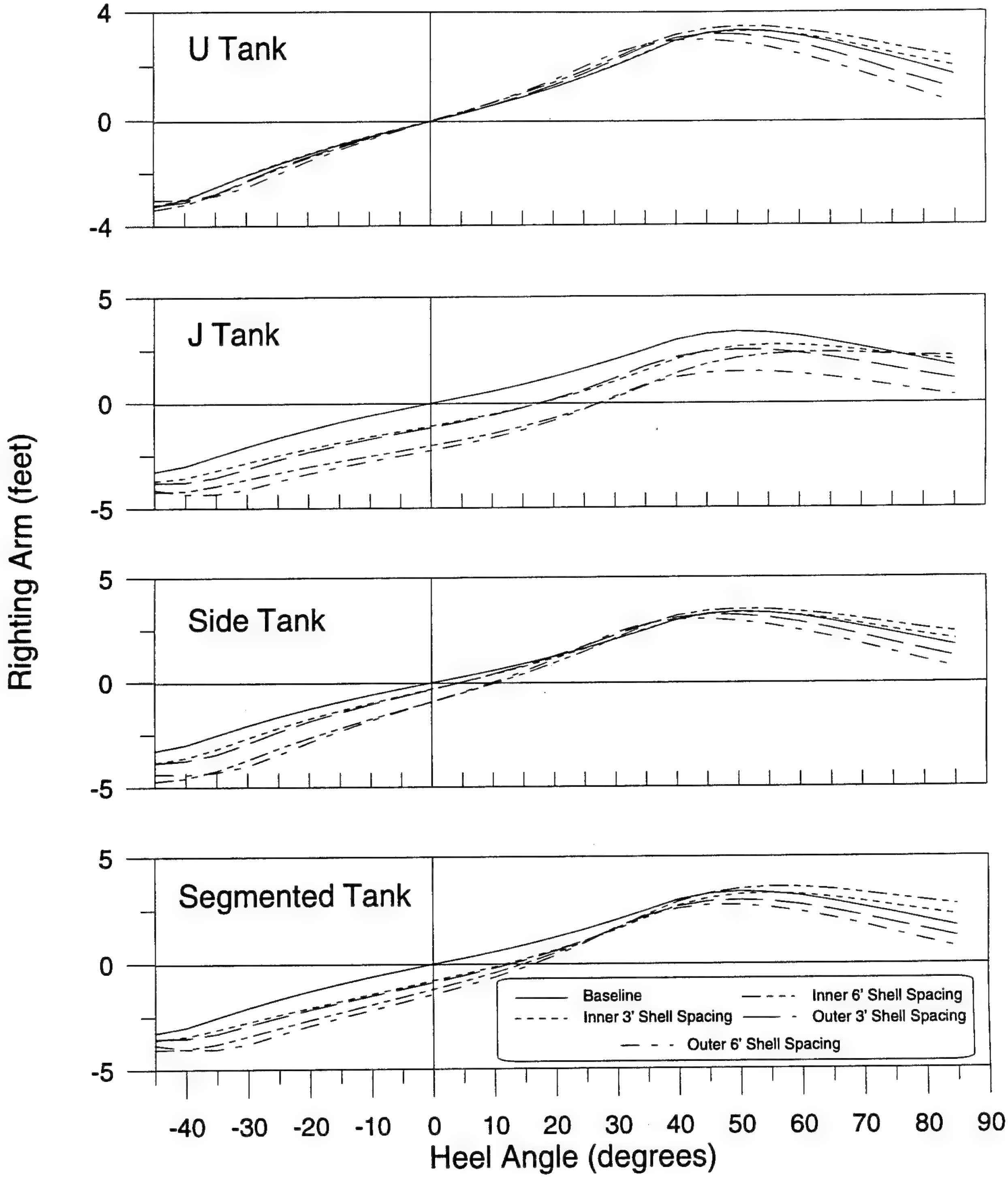


Figure 31. Damage Stability Characteristics by Double Hull Geometry - 60% Bottom Raking Damage

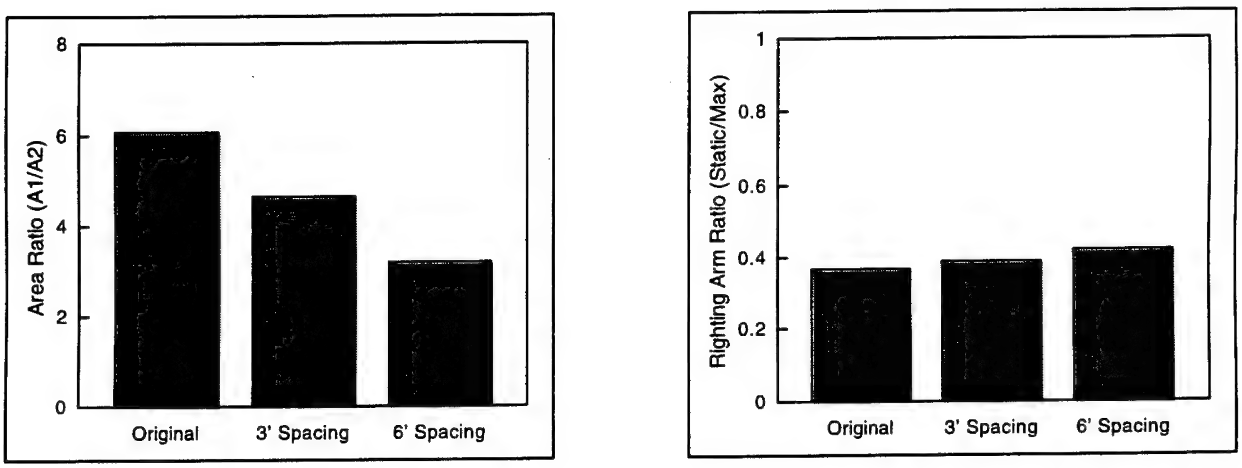


Figure 32. Intact Stability Analysis Using U.S. Navy Criteria Set

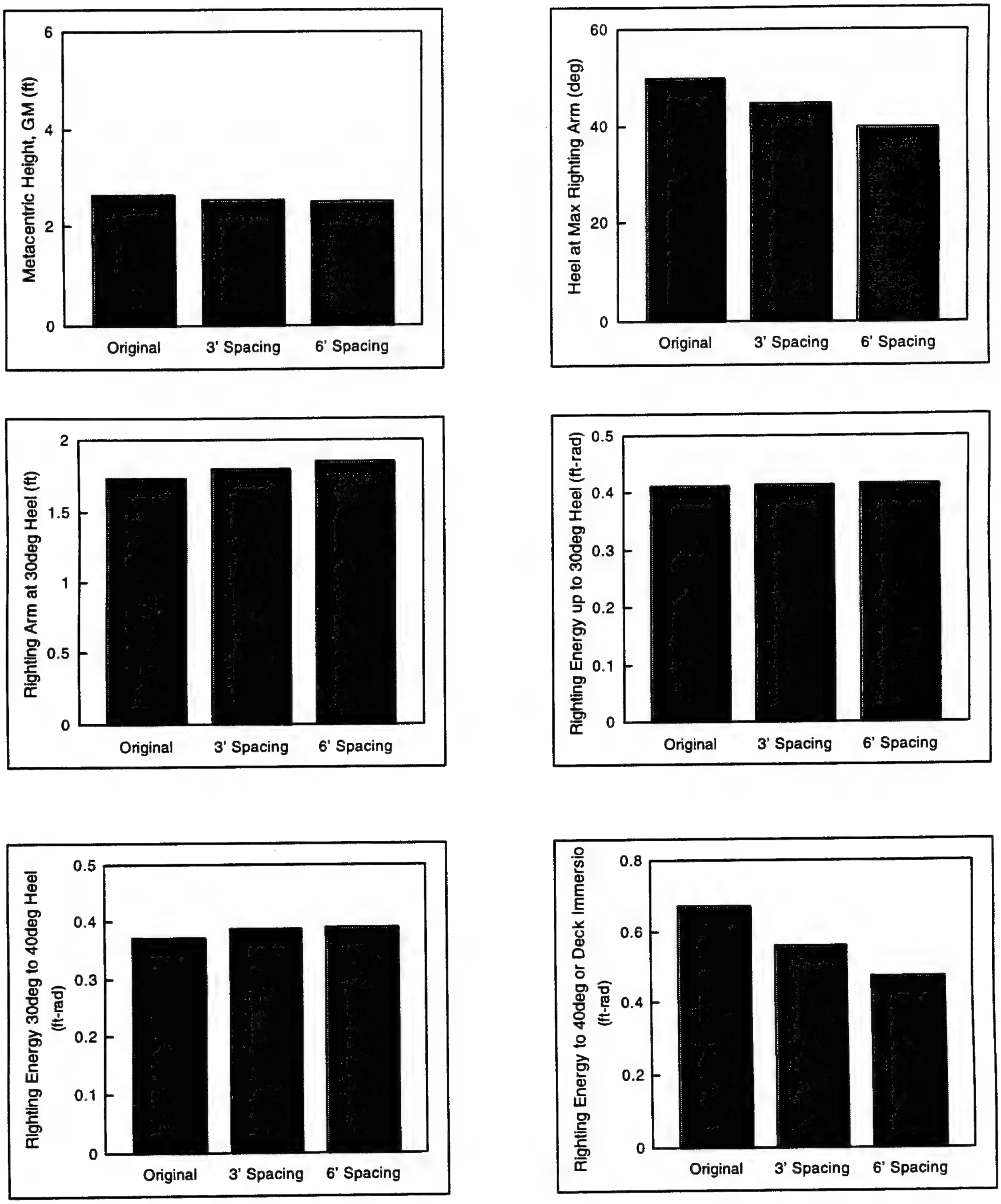
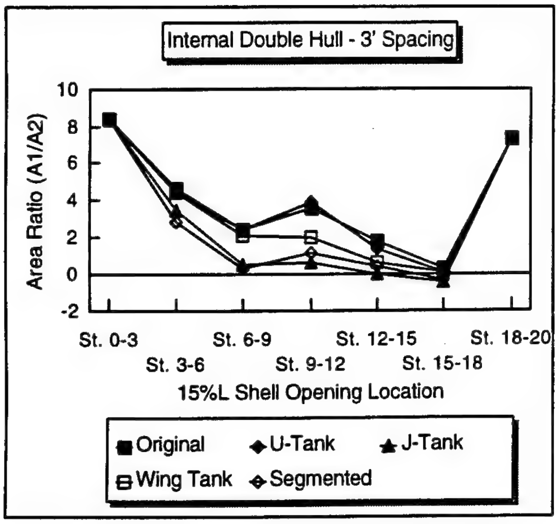
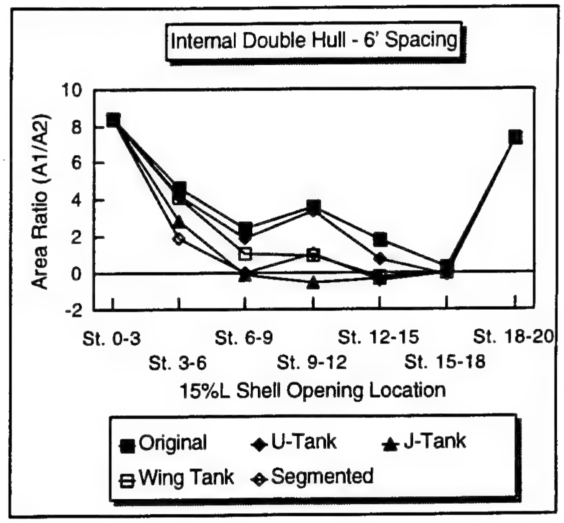
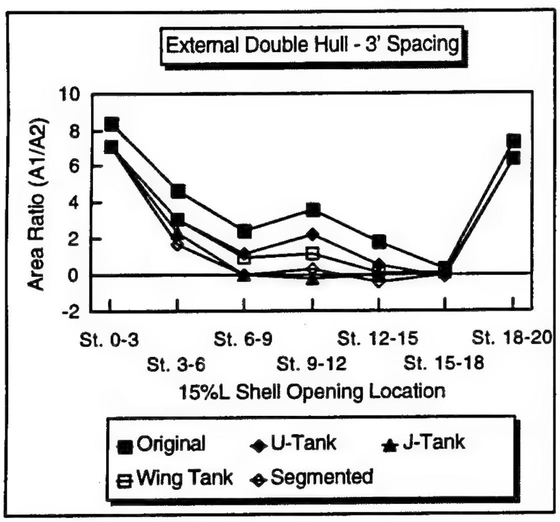


Figure 33. Intact Stability Analysis Using USCG Criteria Set







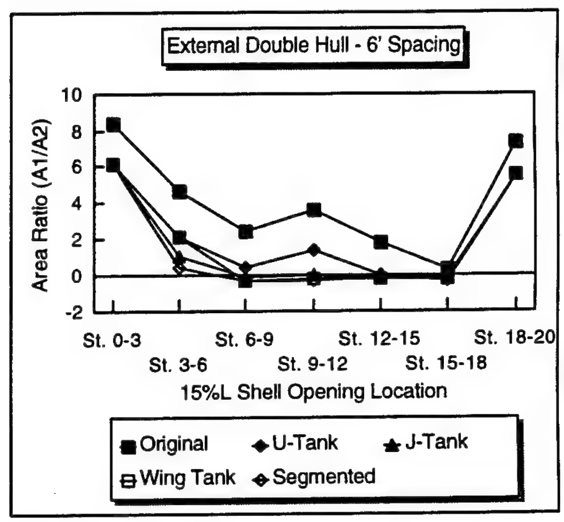


Figure 34. 15%L Shell Opening Damage - Area Ratio Results

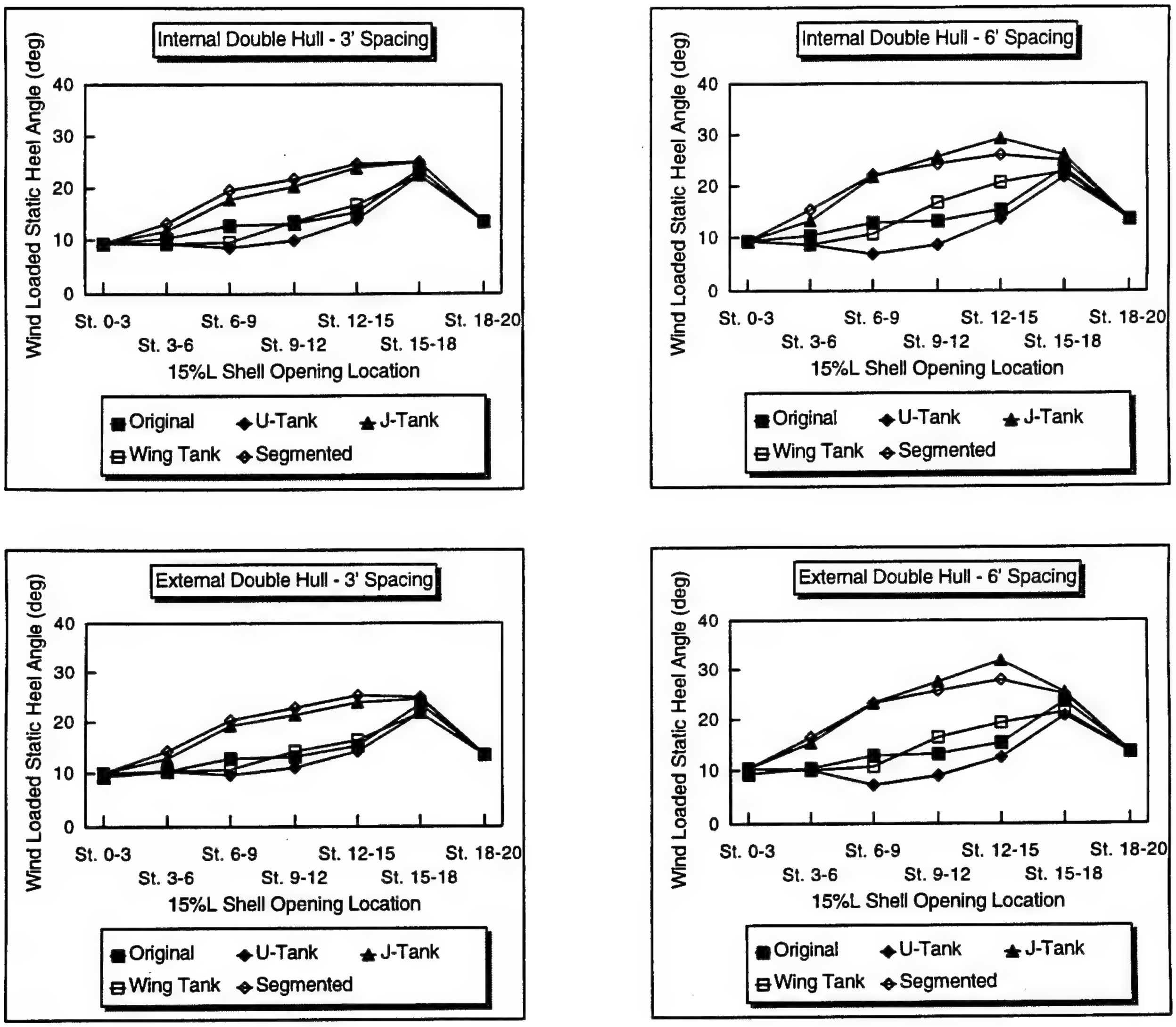


Figure 35. 15%L Shell Opening Damage - Wind Loaded Static Heel Angle Results

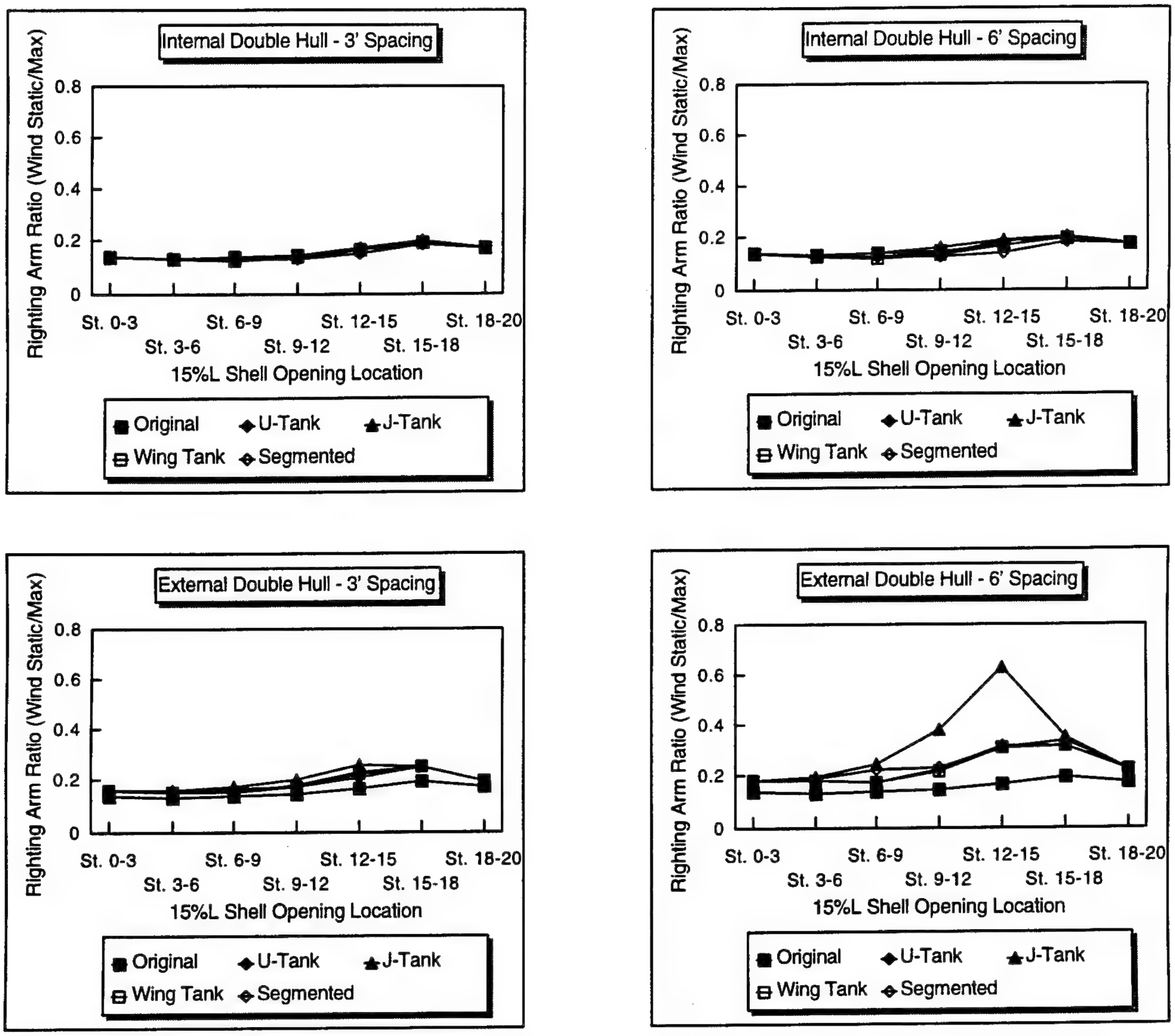


Figure 36. 15%L Shell Opening Damage - Righting Arm Ratio Results

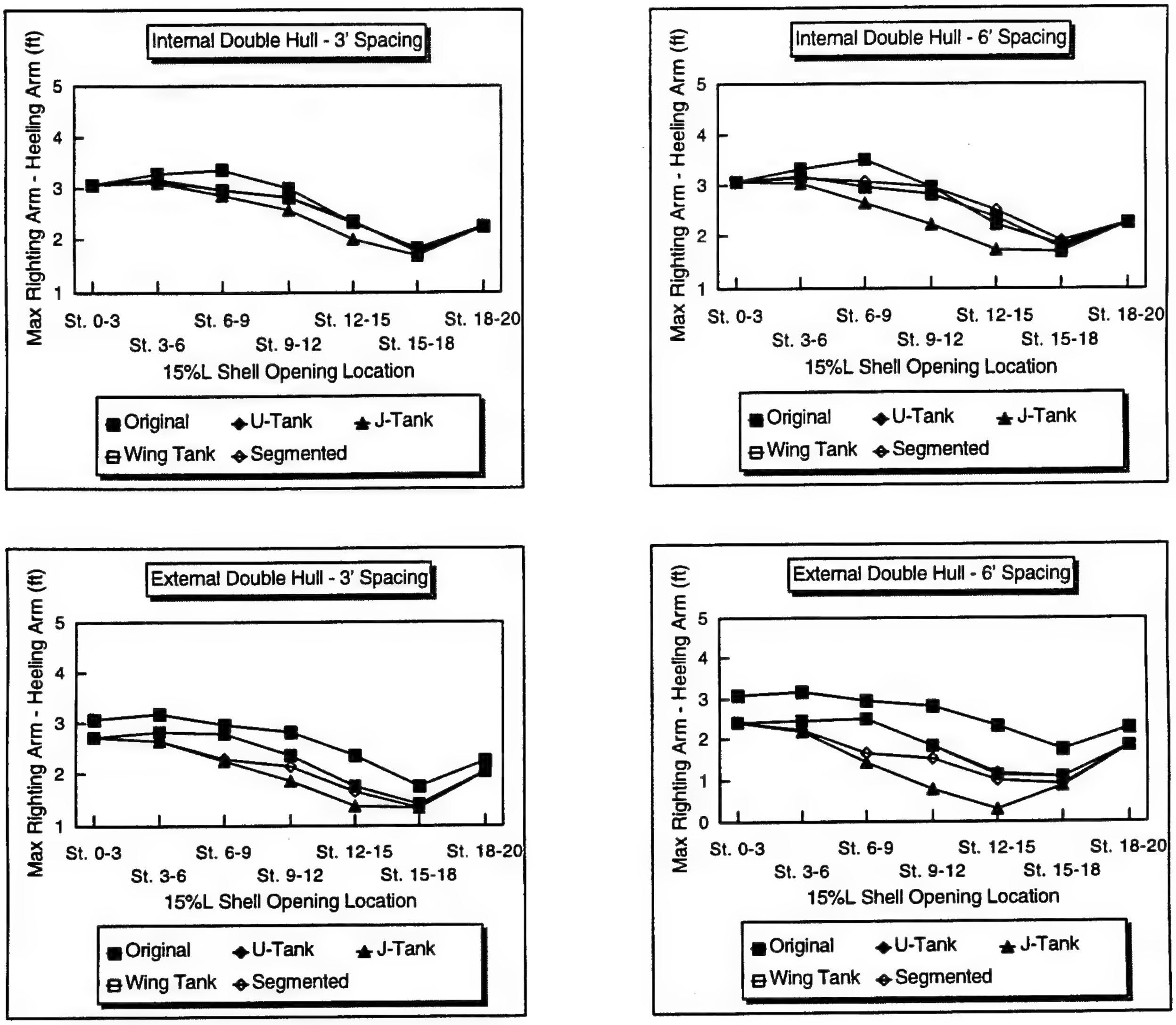


Figure 37. 15%L Shell Opening Damage - Maximum Righting Arm, Heeling Arm Difference Results

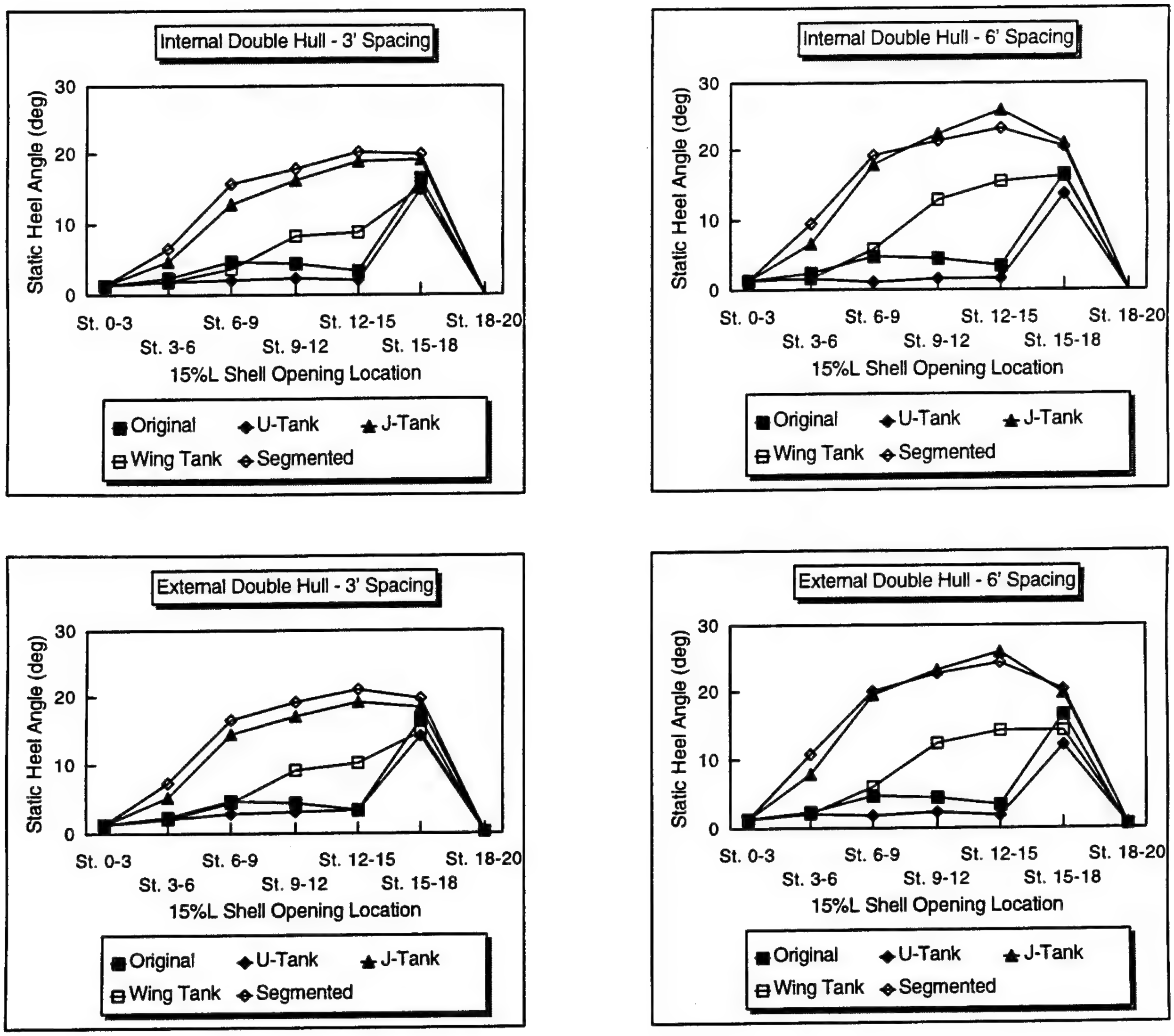


Figure 38. 15%L Shell Opening Damage - Static Heel Angle Results

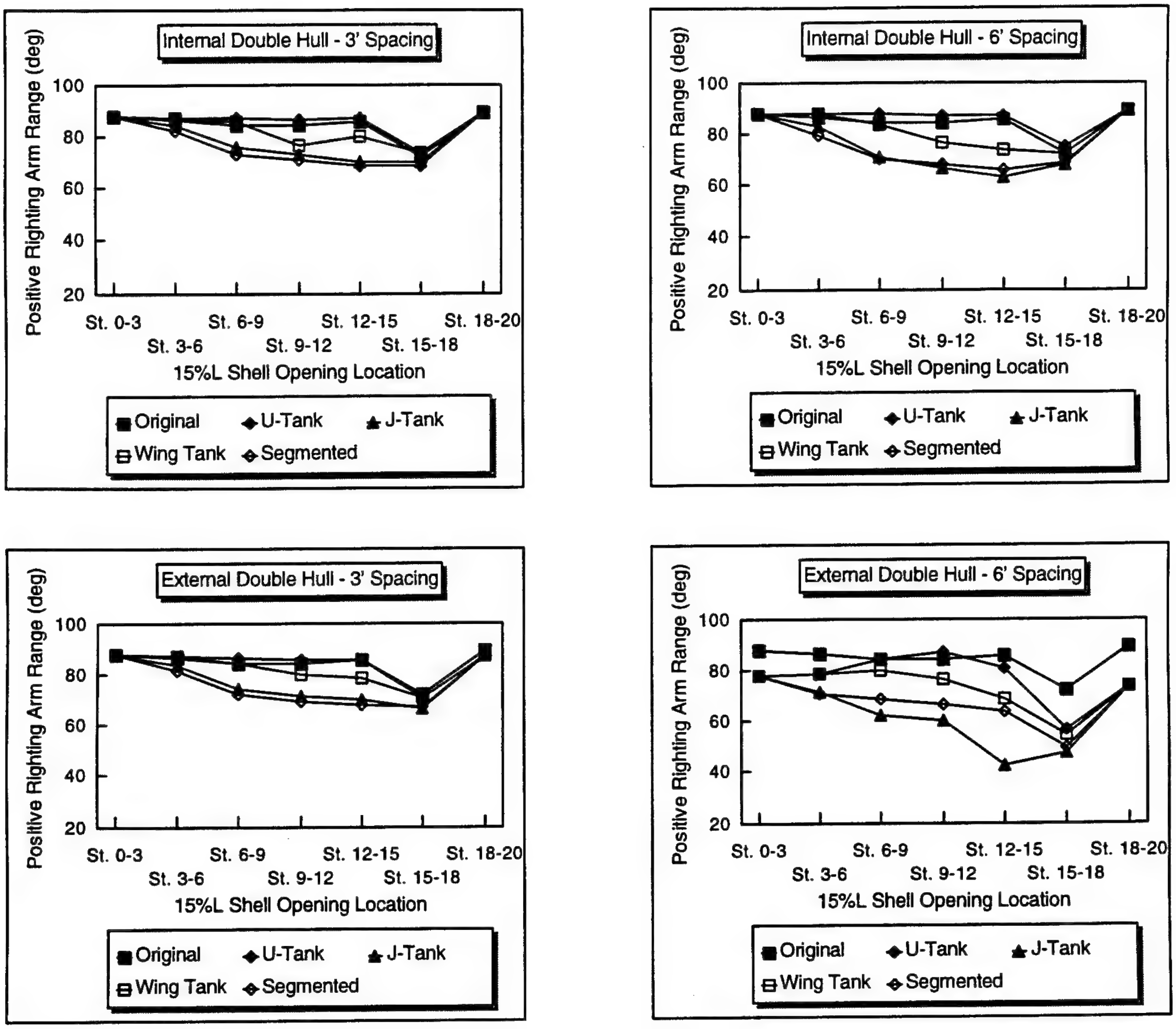


Figure 39. 15%L Shell Opening Damage - Positive Righting Arm Range Results

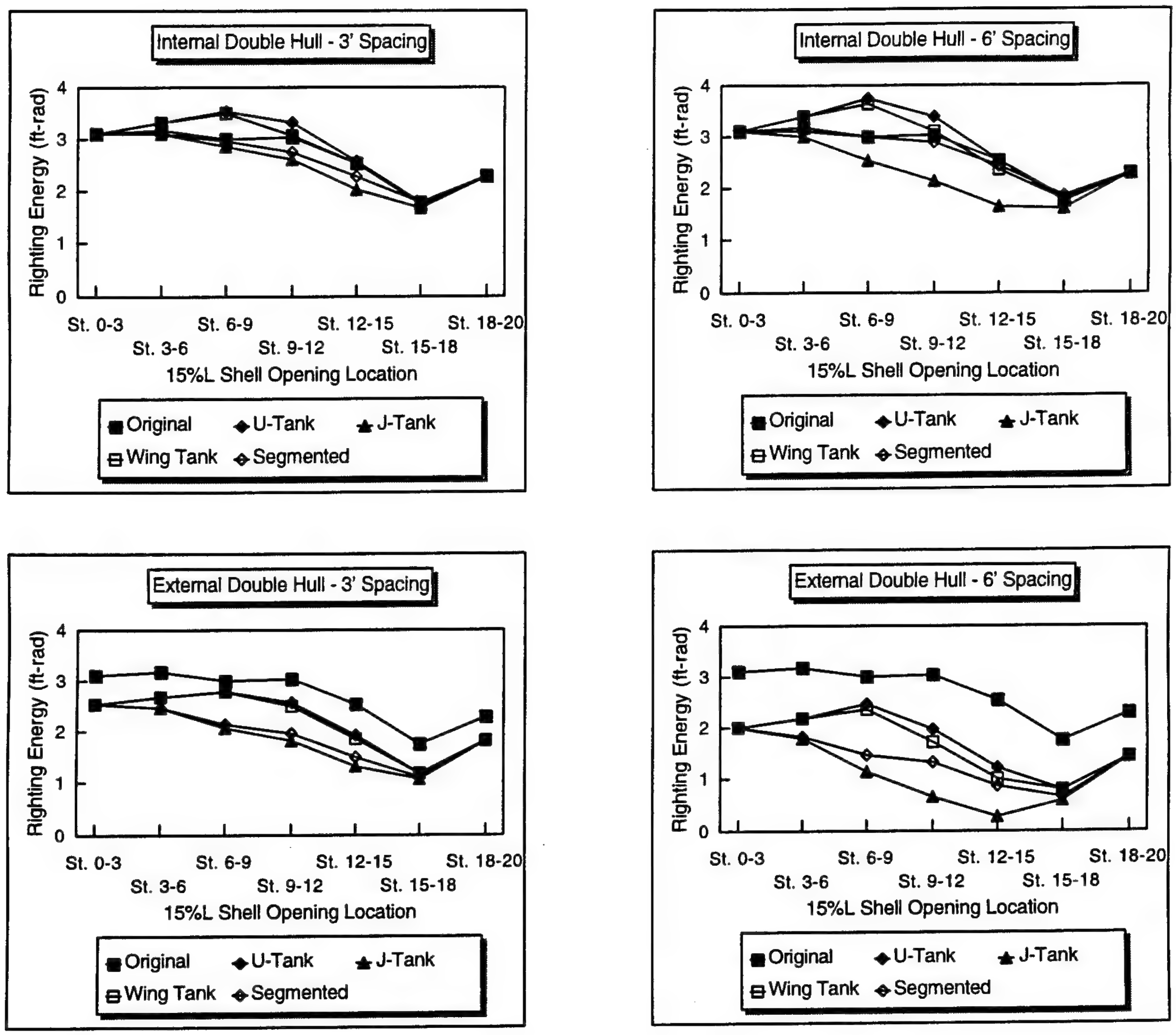


Figure 40. 15%L Shell Opening Damage - Righting Energy Results

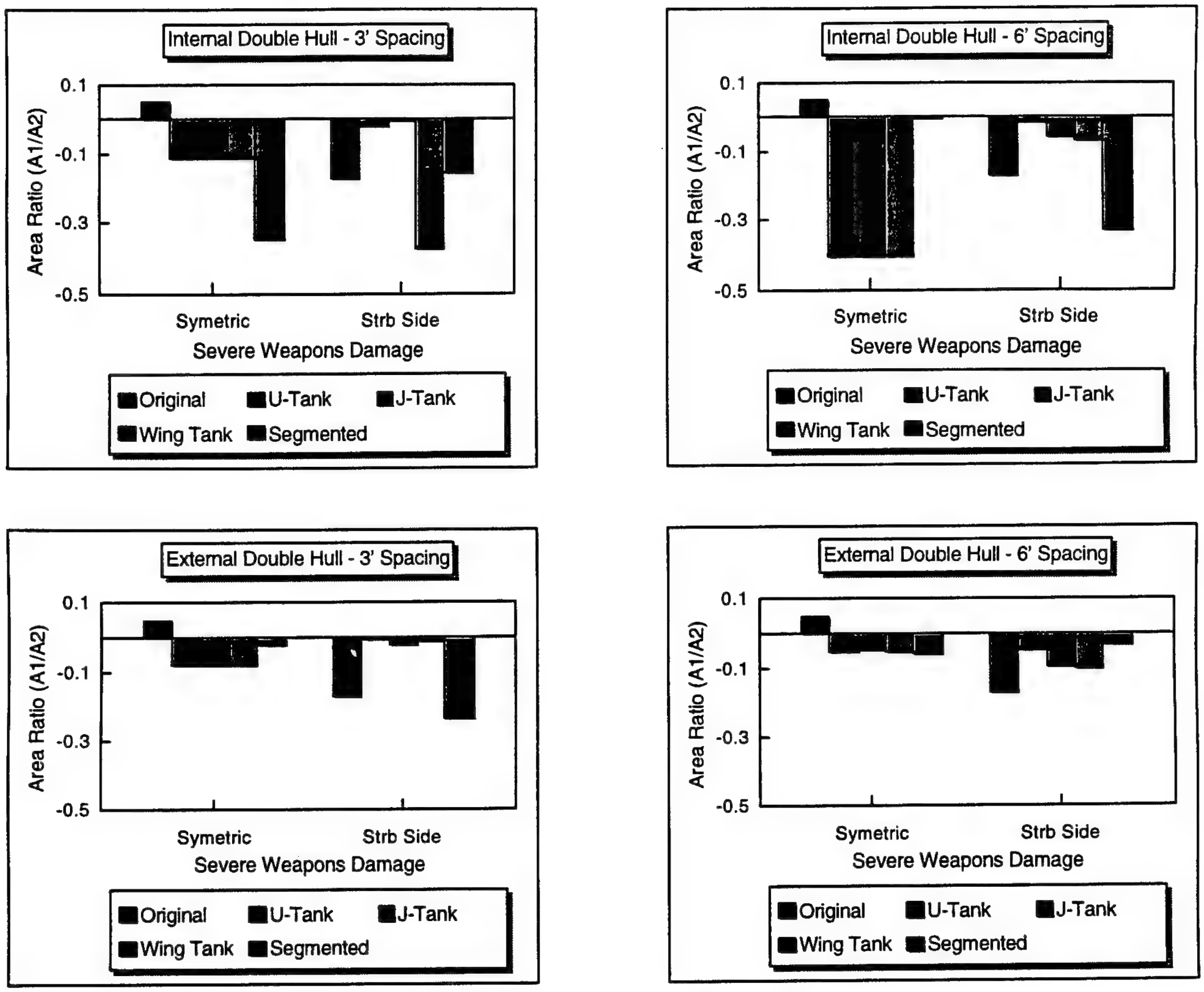


Figure 41. Weapons Damage - Area Ratio Results

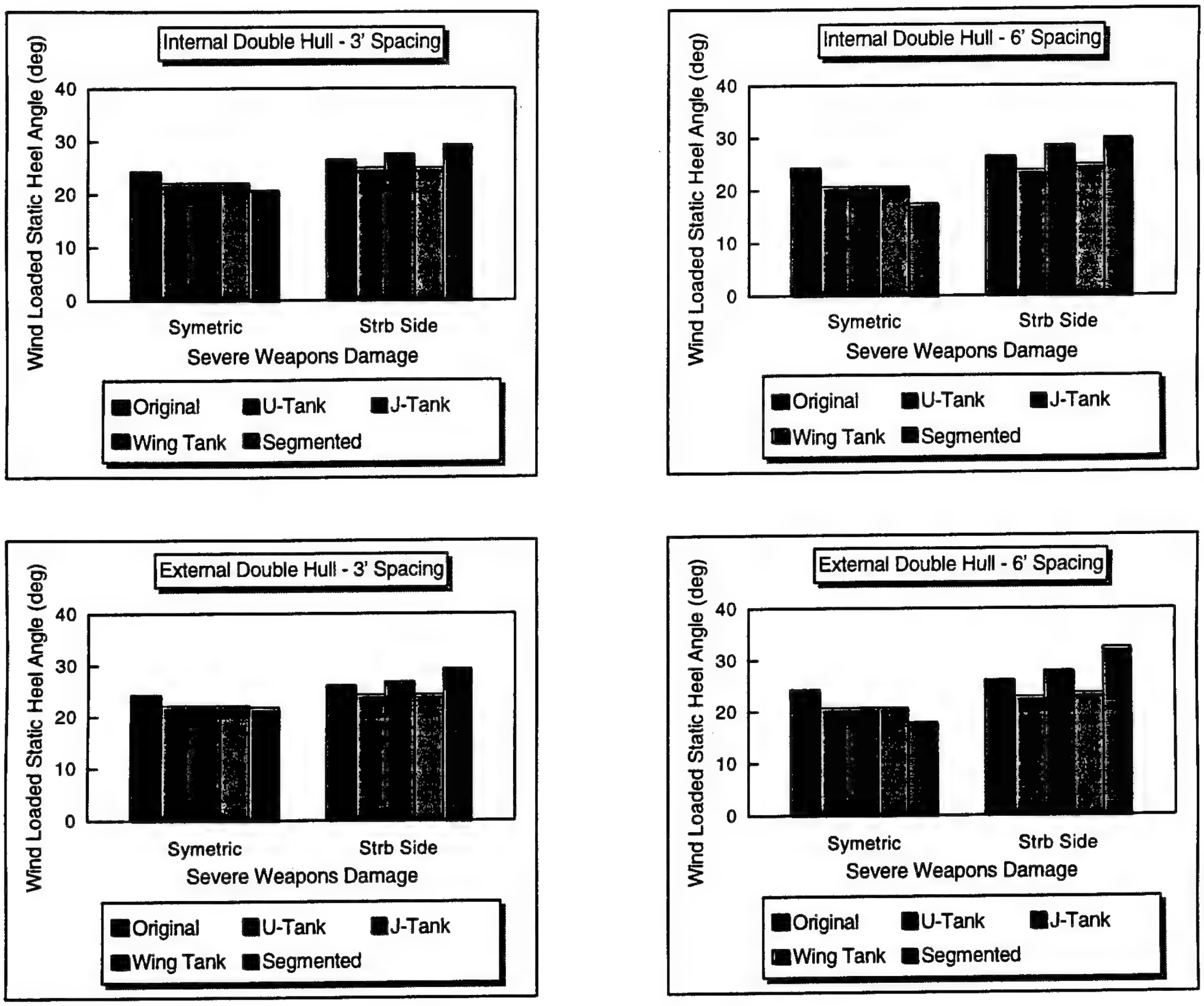


Figure 42. Weapons Damage - Wind Loaded Static Heel Angle Results

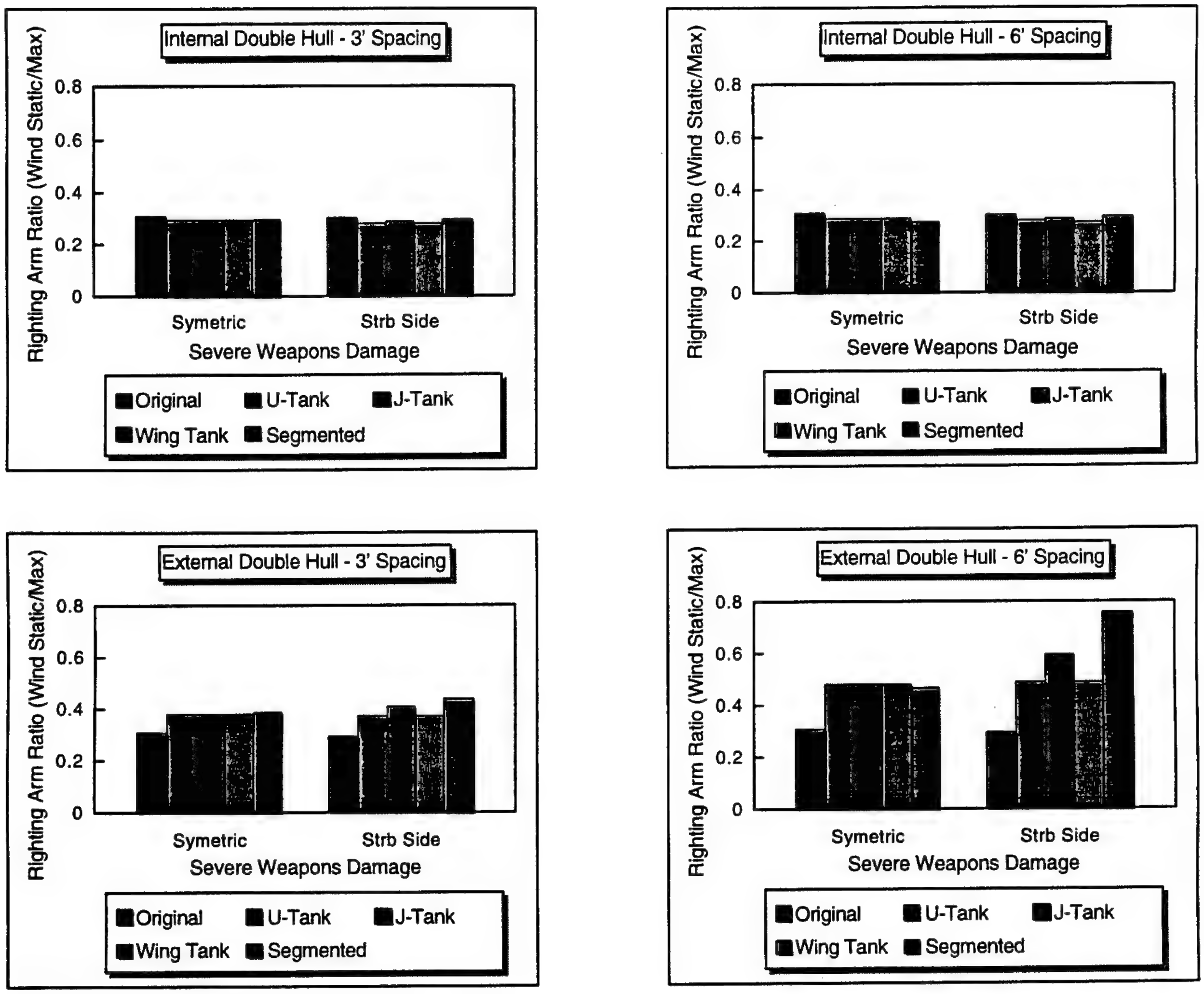


Figure 43. Weapons Damage - Righting Arm Ratio Results

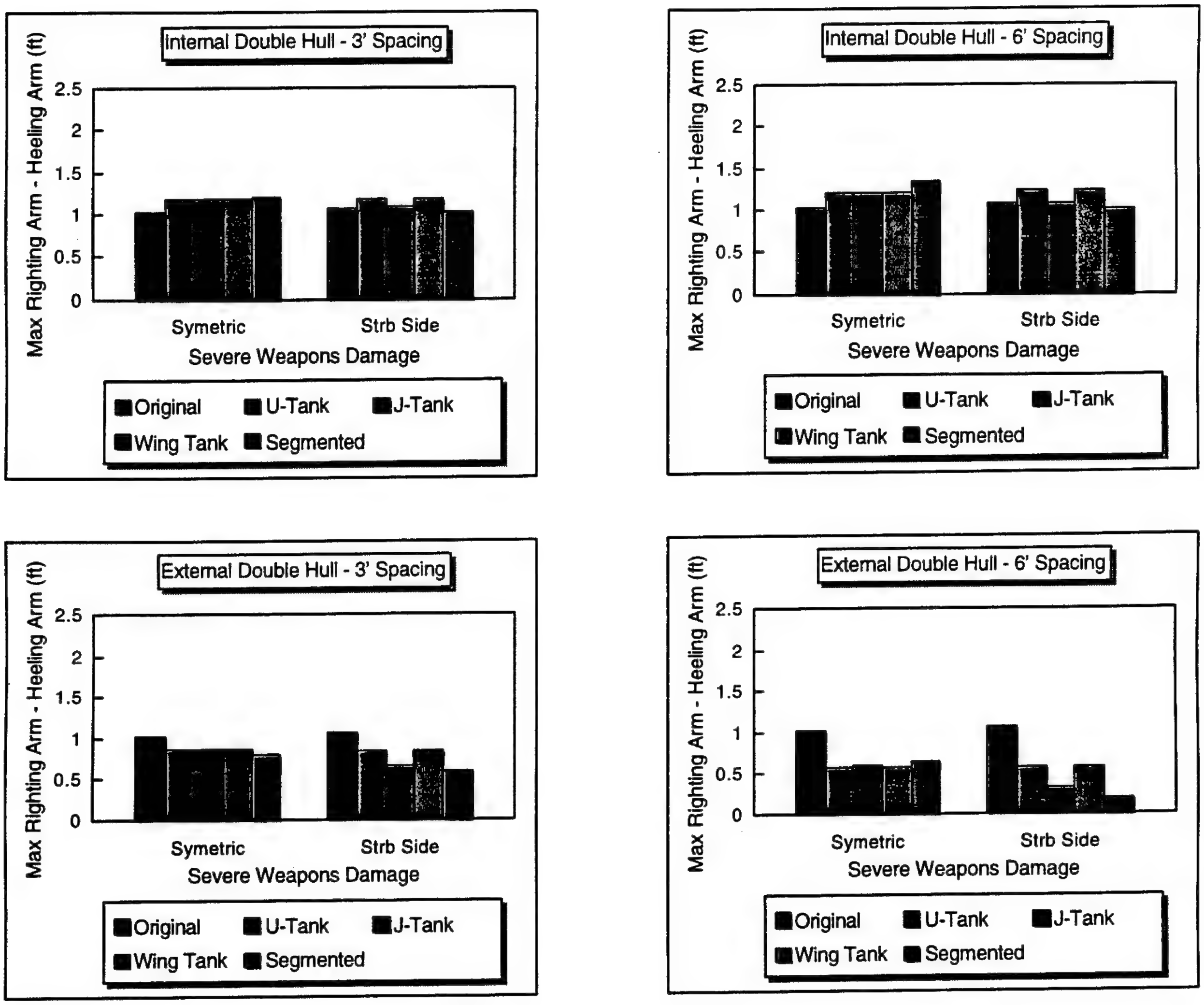


Figure 44. Weapons Damage - Maximum Righting Arm, Heeling Arm Difference Results

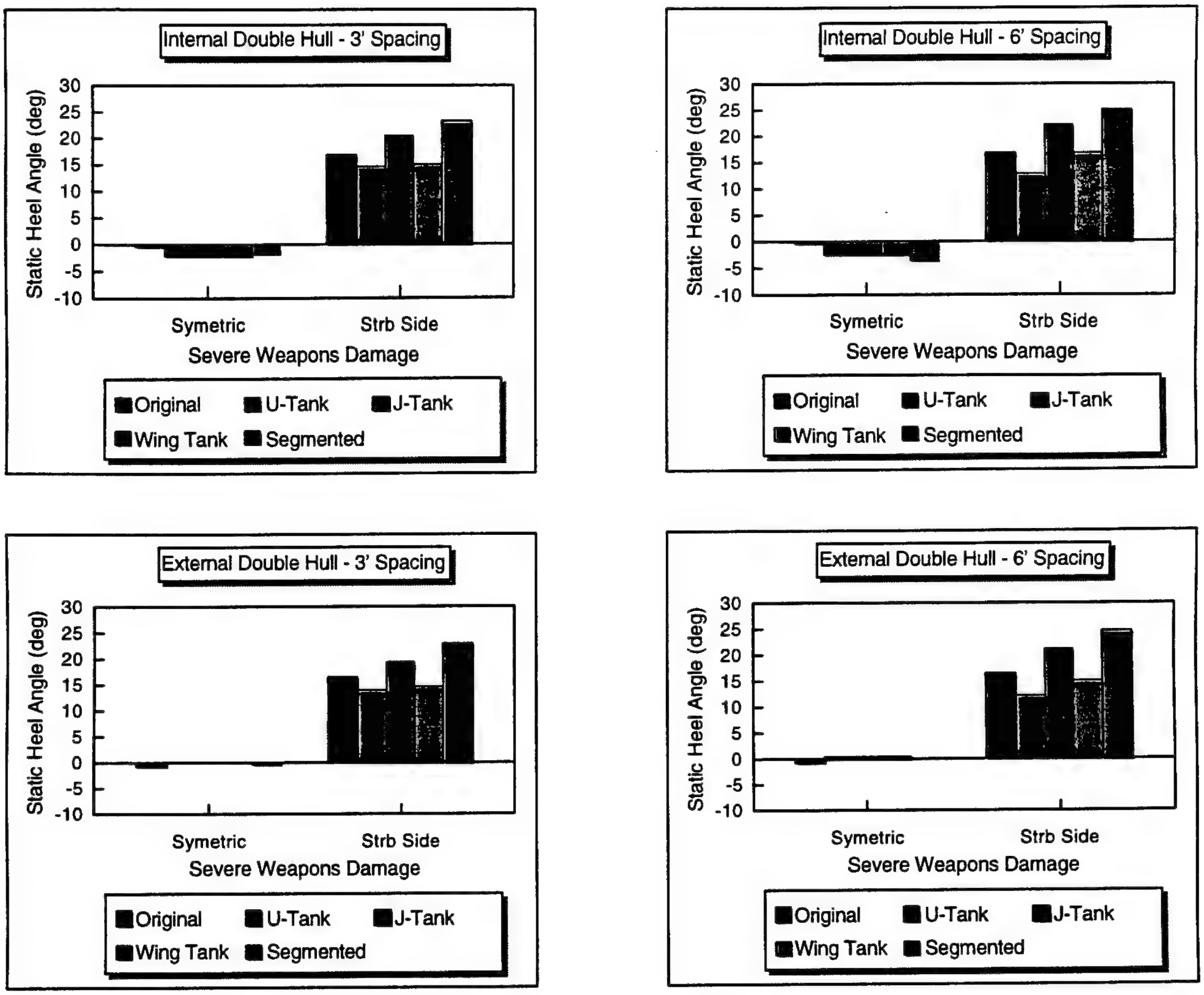


Figure 45. Weapons Damage - Static Heel Angle Results

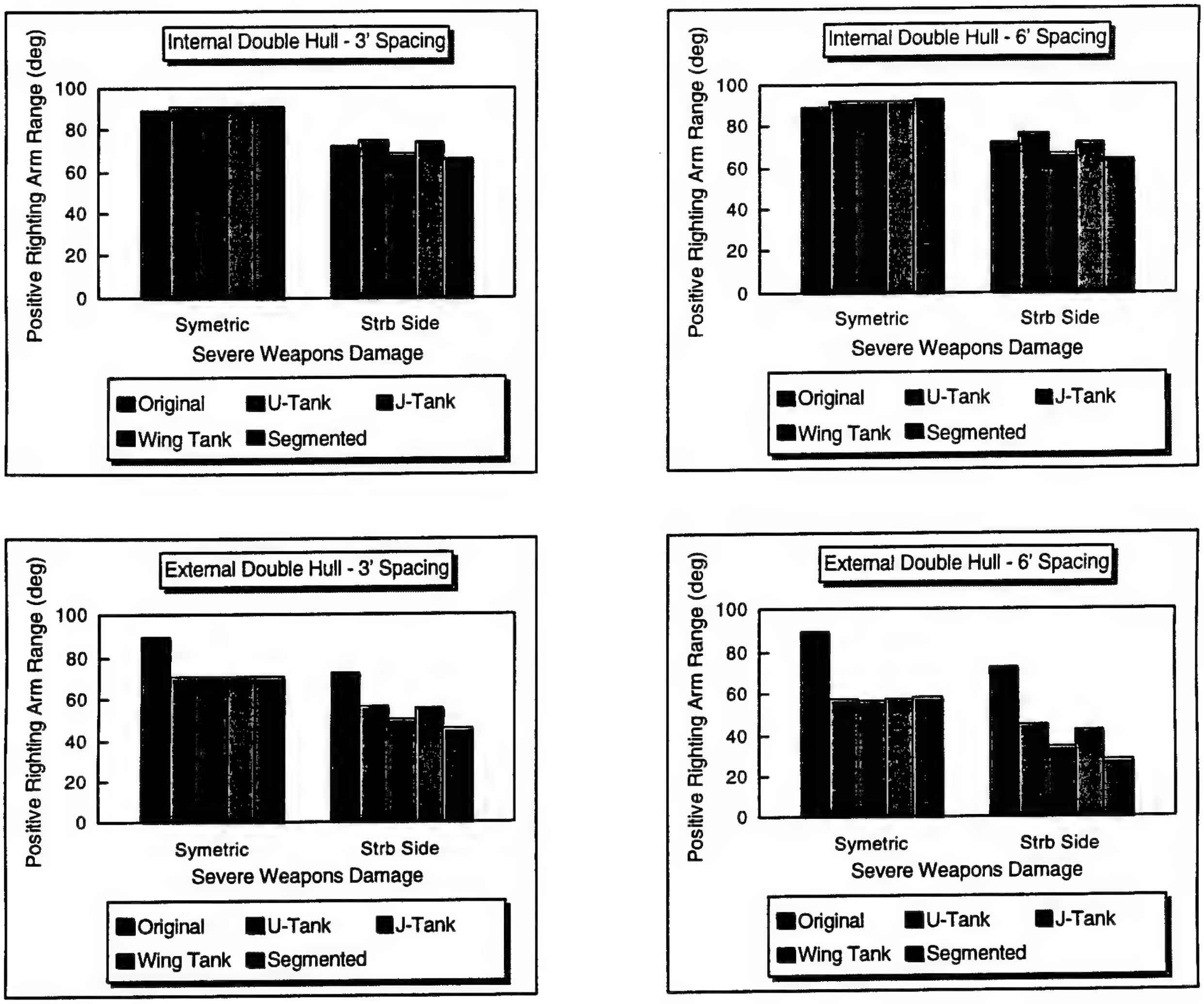
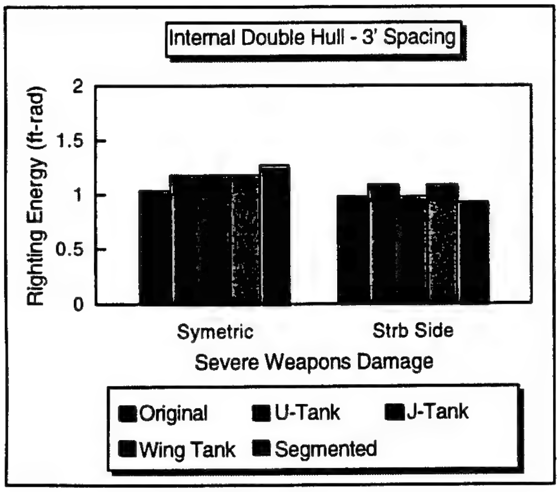
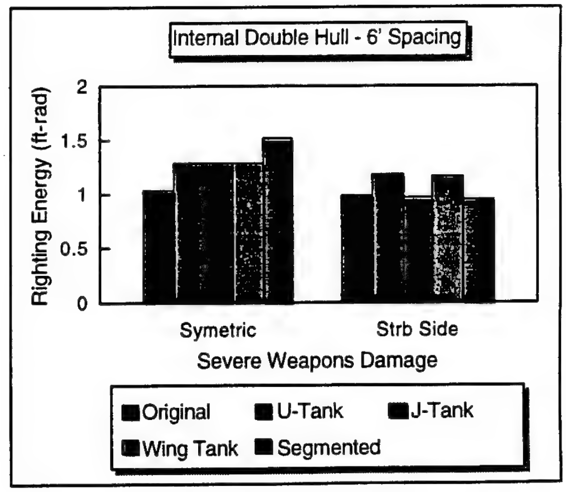
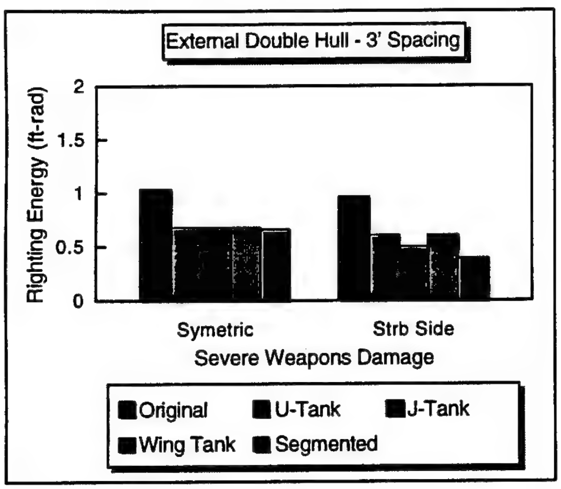


Figure 46. Weapons Damage - Positive Righting Arm Range Results







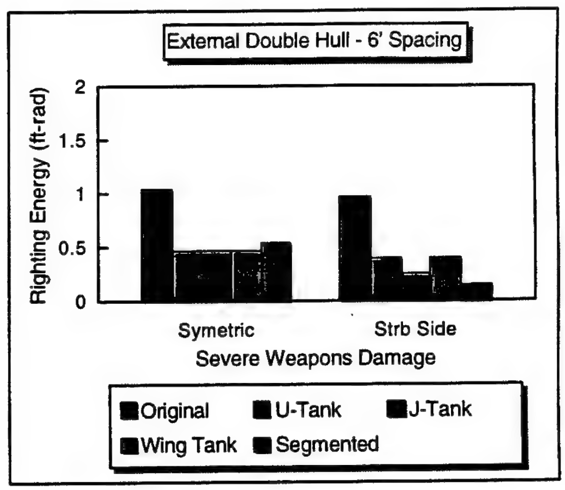


Figure 47. Weapons Damage - Righting Energy Results

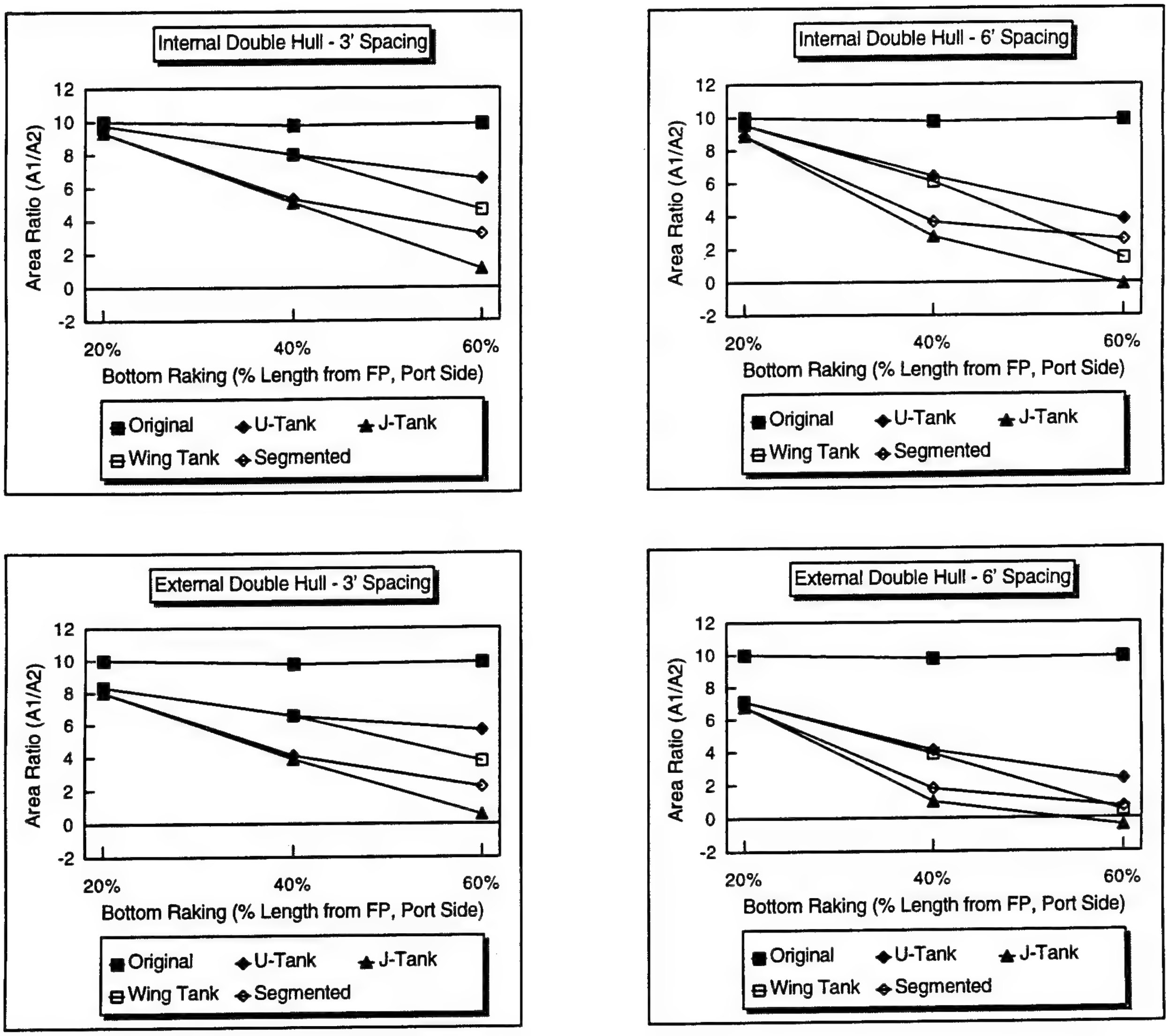


Figure 48. Bottom Raking Damage - Area Ration Results

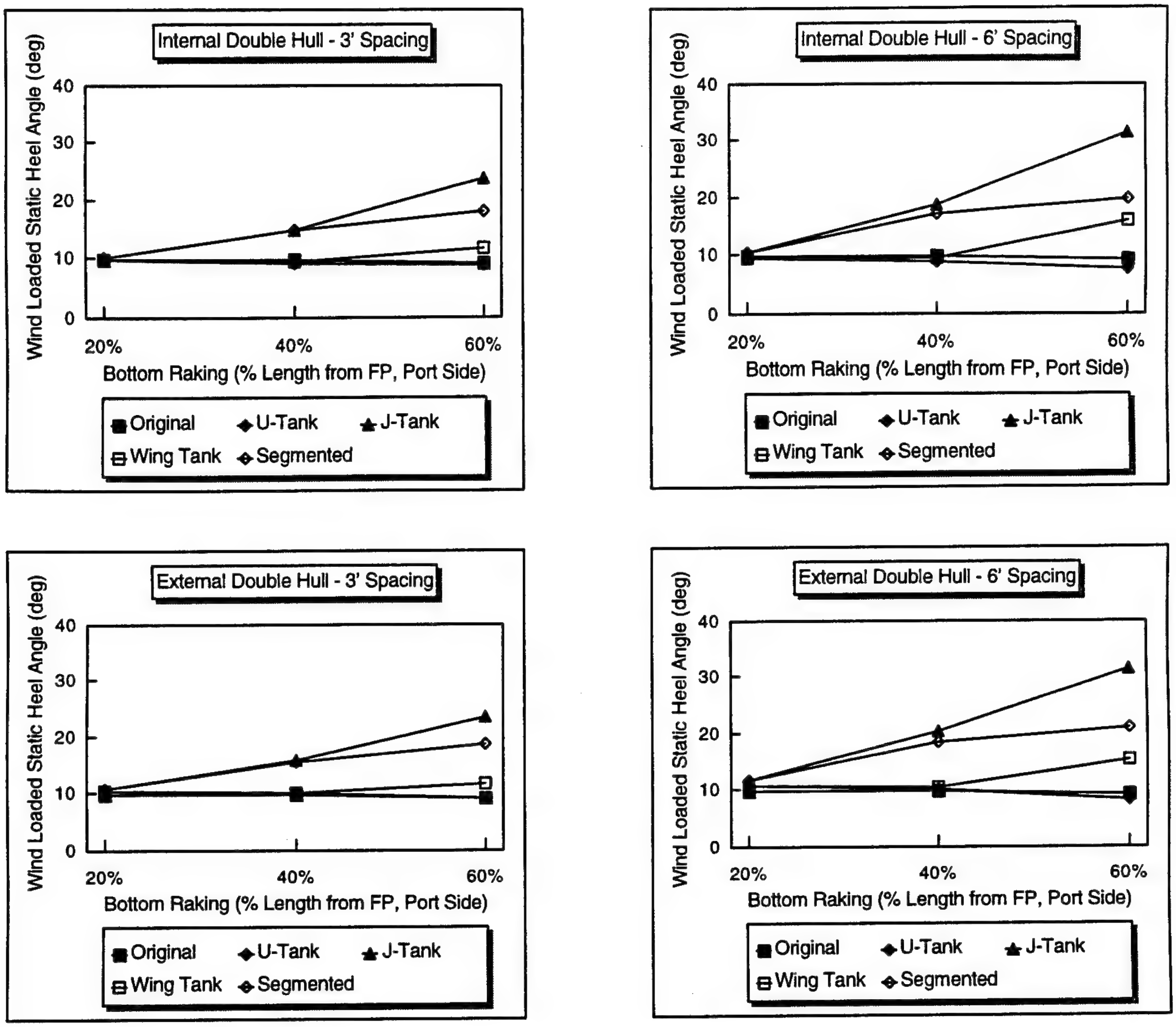


Figure 49. Bottom Raking Damage - Wind Loaded Static Heel Angle Results

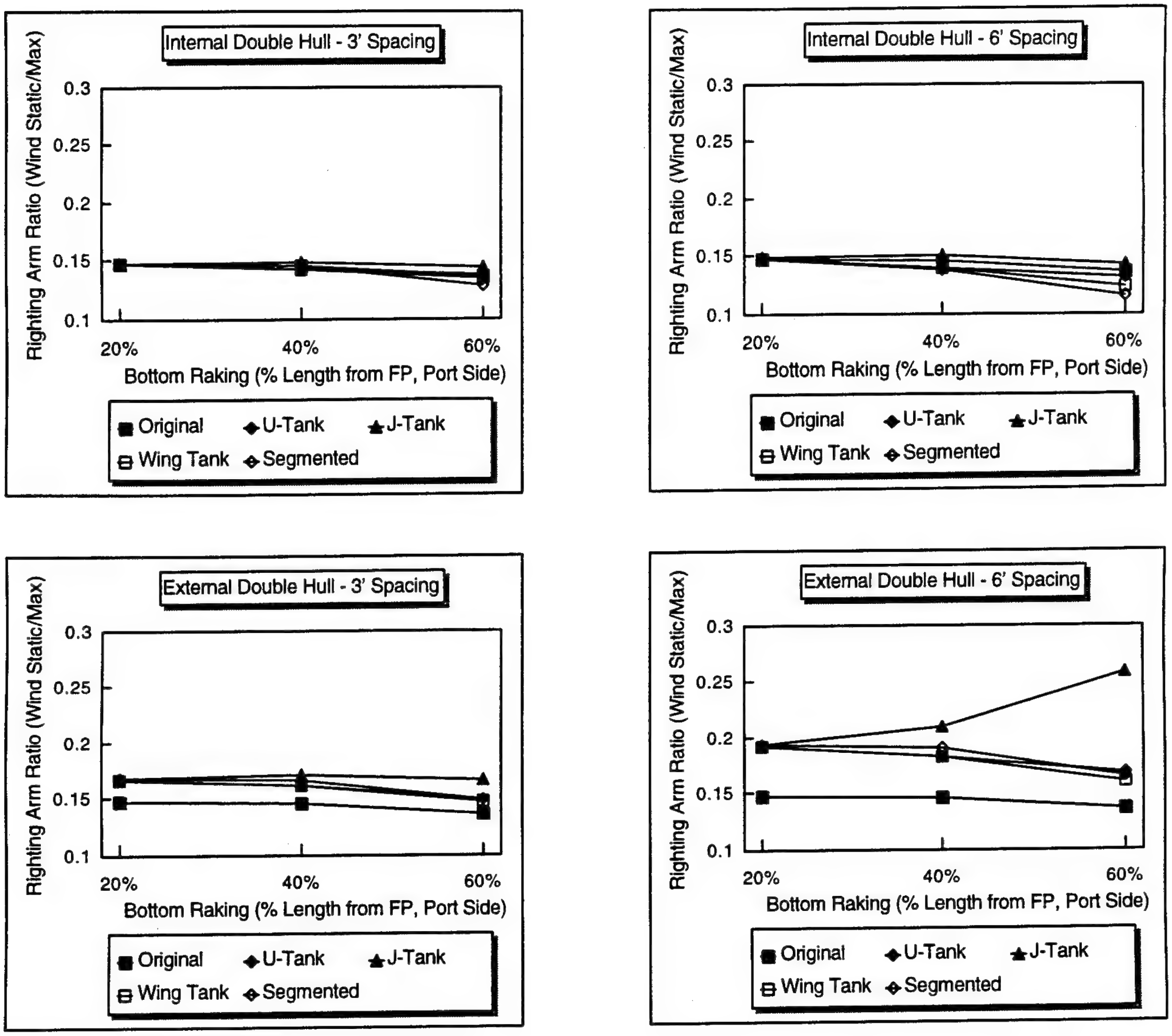


Figure 50. Bottom Raking Damage - Righting Arm Ratio Results

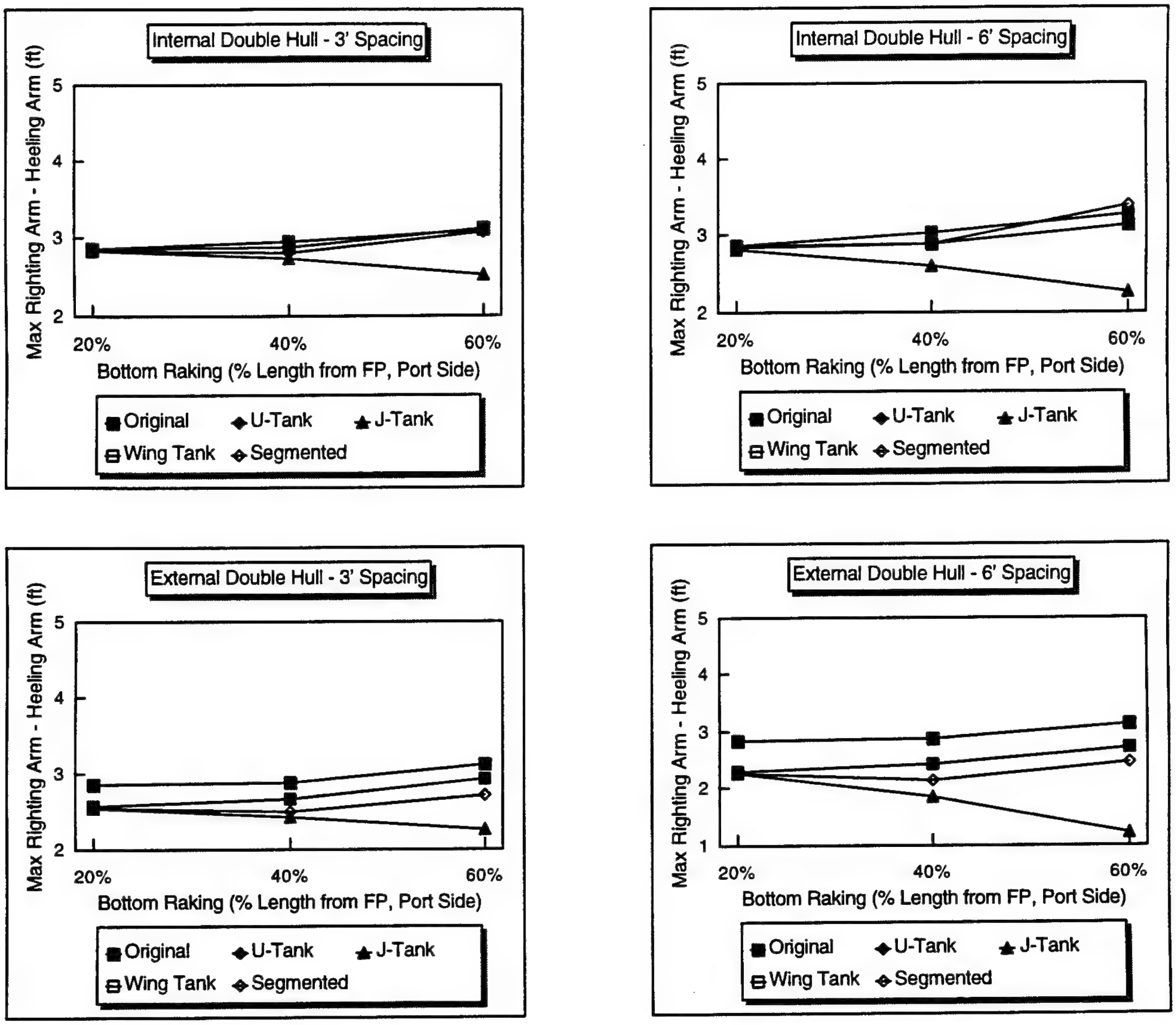


Figure 51. Bottom Raking Damage - Maximum Righting Arm, Heeling Arm Difference Results

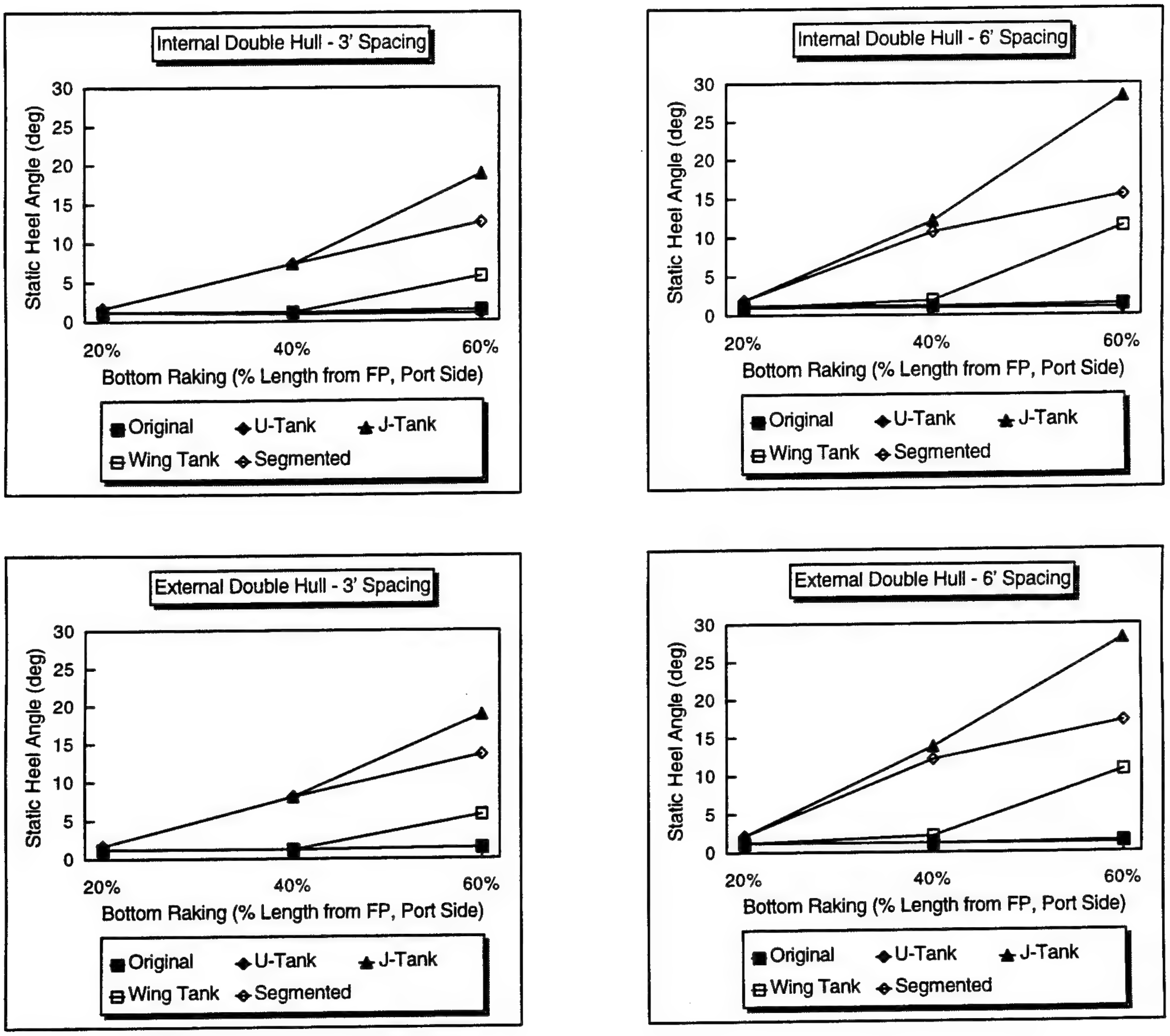


Figure 52. Bottom Raking Damage - Static Heel Angle Results

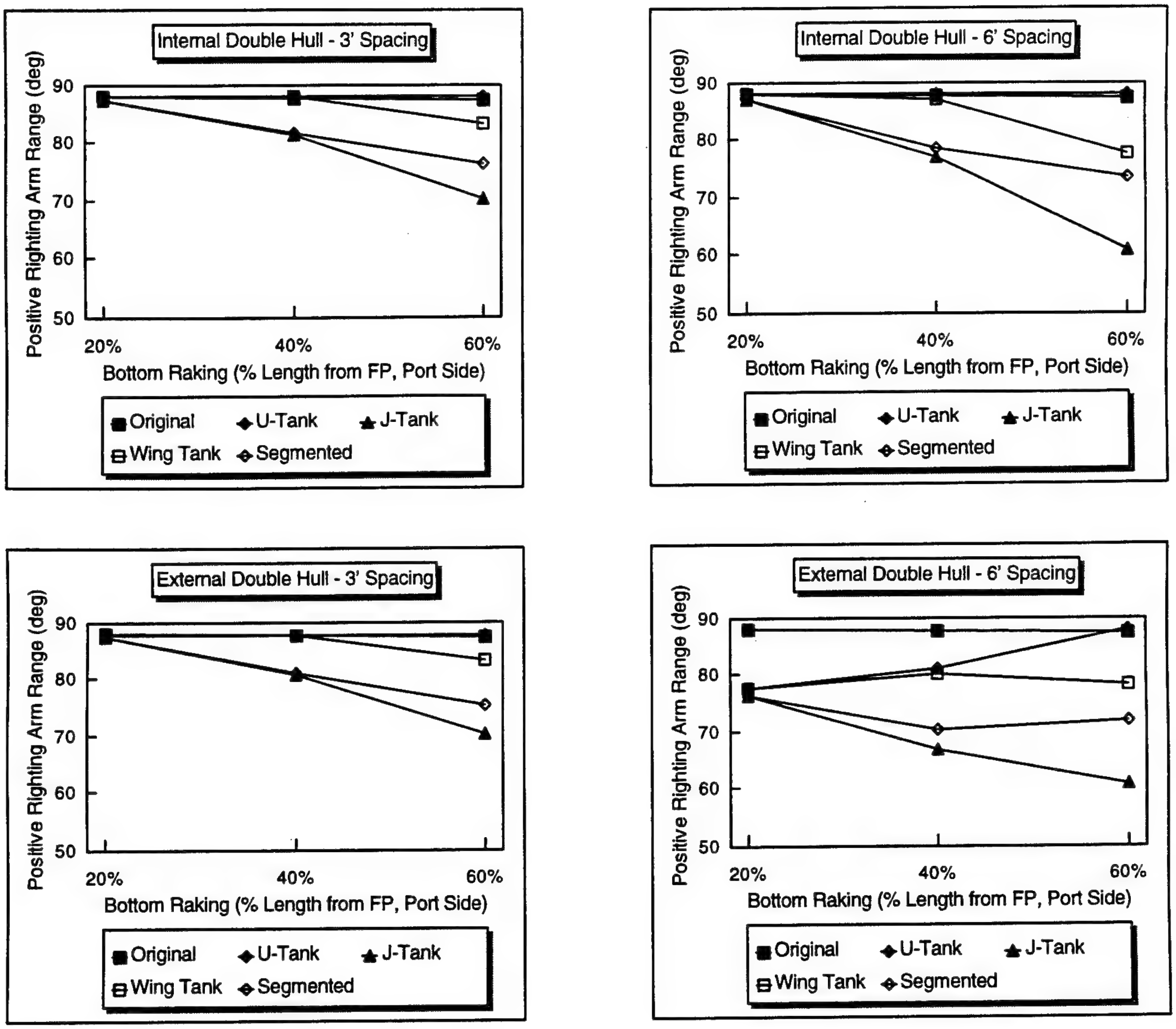


Figure 53. Bottom Raking Damage - Positive Righting Arm Range Results

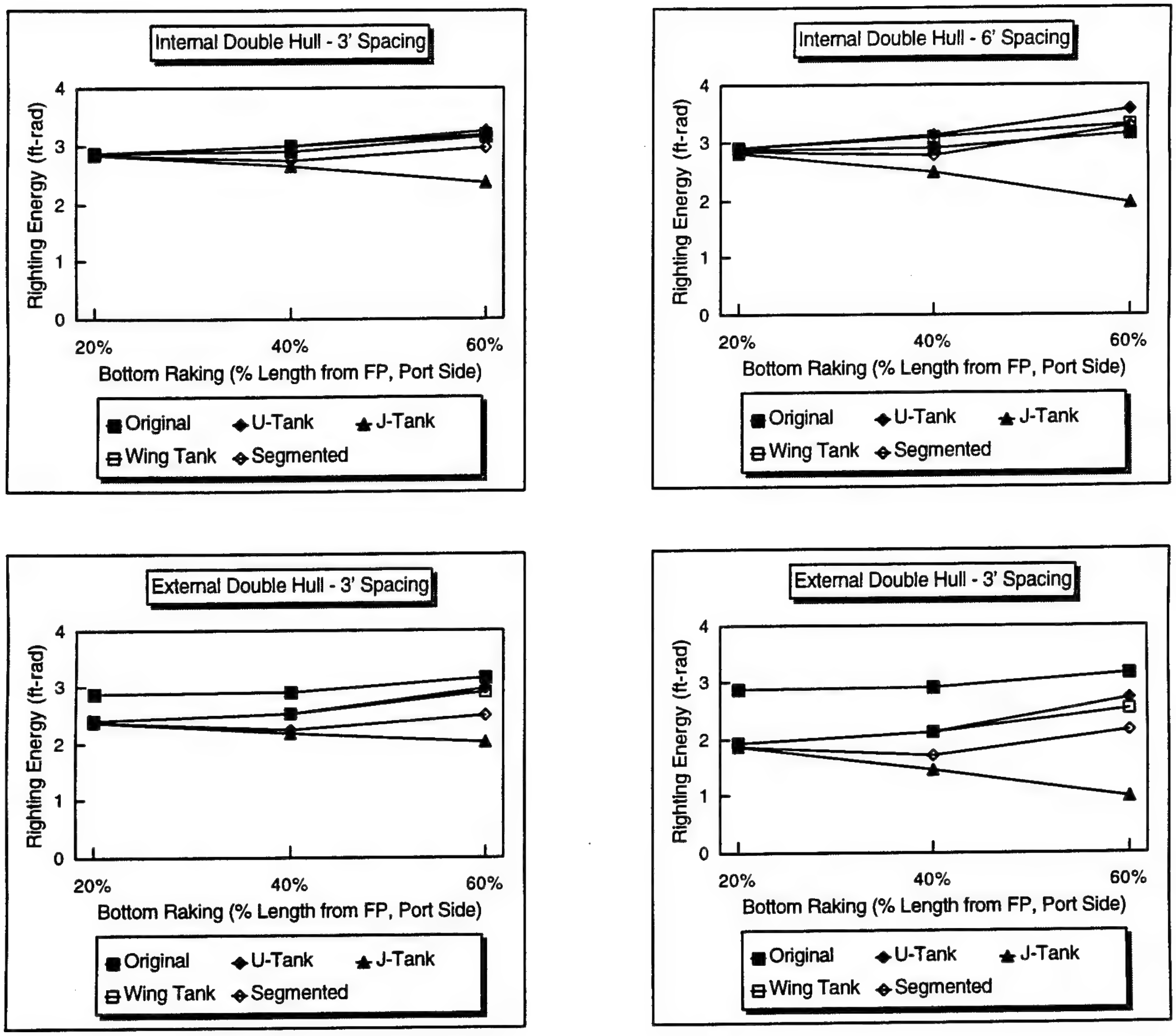


Figure 54. Bottom Raking Damage - Righting Energy Results

Table 1. Ship Particulars

LOA (ft/m)	562 / 171.3		
LWL (ft/m)	531 / 161.8		
LPP (ft/m)	529 / 161.2		
Draft (ft/m)	22.22 / 6.77		
KG (ft/m)	23.42 / 7.14		
	Original CG 47	3' Shell spacing	6' Shell Spacing
Displacement (LT)	9561	11531	13722
L_{cg} (ft/m fwd midship)	-9.89 / -3.01	-10.8 / -3.29	-11.47 / -3.5
Maximum Beam (ft/m)	55.3 / 16.85	61.3 / 18.68	67.3 / 20.51
Cp	0.601	0.508	0.565
C_b	0.514	0.560	0.607

Table 2. Summary of U.S. Navy Stability Criteria Investigated

Intact Criteria

- 100 knot beam wind imposed, 25 degree roll back angle
- Righting arm at static wind loaded heel angle is no more than 60% of the maximum righting arm
- Area ratio (A1/A2) is no less than 140%

Damage Condition Criteria

- 100 knot beam wind and roll back angle reduced according to displacement
- Area ratio (A1/A2) is no less than 140%
- Righting arm minus heeling arm at the maximum righting arm value is no less than 0.25ft
- Static wind loaded heel angle of less than 15 degrees, if side protection system used, 20 degrees with capability to reduce heel to less than 5 degrees
- Shell opening of 15% of the length of the vessel at any longitudinal location, centerline to main deck
- Weapons damage condition

Table 3. Summary of U.S. Coast Guard Double Hull Tanker Specific Stability Criteria Investigated

Intact Criteria

- Initial GM no less than 1.5 m
- Righting arm grater than 0.2m at 30 degrees heel with the maximum righting arm occurring at no less than 25 degrees heel
- Righting energy greater than 0.055 m-rad up to 30 degrees heel
- Righting energy greater than 0.03 m-rad between 30 and 40 degrees heel
- Righting energy greater than 0.09 m-rad up to 40 degrees heel or downflooding angle, which ever is less

Damage Condition Criteria

- Static heel angle less than 25 degrees
- Positive righting arm range of at least 20 degrees beyond the static heel angle
- Righting energy no less than 0.0175 m-rad
- Bottom raking damage of 40% or 60% of the length of the vessel, depending on displacement

Table 4. Intact Stability Evaluation Results

	Original	3' Spacing	6' Spacing
Static Heel (deg)	0	0	0
Maximum Righting Arm (ft)	2.896	2.712	2.499
Heel at Max Righting Arm (deg)	50	45	40
Wind Static Heel (deg)	20.2058	20.2074	20.1524
Righting Arm at Wind Static Heel (ft)	1.0566	1.0566	1.0574
Max Heel (deg)	37.181	34.0886	31.5443
St. Immersed at Max Heel	8.318	8.318	8.318
Min Heel (deg)	-37.1932	-34.1794	-31.4633
St. Immersed at Min Heel	8.318	8.318	8.318
Max Heel total (deg)	24.1711	24.1796	24.2463
St. Immersed at Max Heel total	17.003	17.003	17.003
Min Heel total (deg)	-24.3223	-24.3373	-24.2753
St. Immersed at Min Heel total	17.003	17.003	17.003
Roll Back (deg)	25	25	25
GM (ft)	2.6471	2.5669	2.5096
Righting Arm - Heeling Arm @ Max RA (ft)	2.4	2.112	1.795
Righting Arm at 30deg (ft)	1.731	1.791	1.853
Righting Energy, A1 (ft-rad)	2.0479	1.5834	1.0298
Heeling Energy, A2 (ft-rad)	0.3385	0.3406	0.3434
Area Ratio, A1/A2	6.05	4.6484	2.9989
Righting Arm Ratio	0.3648	0.3896	0.4231
Righting Energy to 30deg (ft-rad)	0.4132	0.415	0.4186
Righting Energy 30 to 40deg (ft-rad)	0.3711	0.3865	0.3898
Righting Energy to 40deg or Max Heel (ft-rad)	0.6697	0.5588	0.4744

Table 5. Damage Stability Evaluation Results for Original CG 47

	15% L Shell Opening Along Ship							Severe Weapons		Bottom Raking		
	St. 0-3	St. 3-6	St. 6-9	St. 9-12	St. 12-15	St. 15-18	St. 18-20	Symetric	Strb. Side	20%	40%	60%
Static Heel (deg)	1.2124	2.3991	4.6909	4.4398	3.4058	16.5982	-0.0319	-0.5394	16.7364	1.108	1.2836	1.4759
Maximum Righting Arm (ft)	3.2569	3.3679	3.1549	3.0109	2.5063	1.9659	2.4619	1.2476	1.2449	3.0389	3.0659	3.3019
Heel at Max Righting Arm (deg)	50	50	50	50	55	50	50	45	50	50	50	50
Wind Static Heel (deg)	9.2675	10.3529	12.9478	13.2852	15.6058	23.6221	13.6538	24.343	26.3567	9.8163	9.8544	9.217
Righting Arm at Wind Static Heel (ft)	0.4482	0.4455	0.4367	0.4355	0.4269	0.3861	0.4343	0.382	0.3694	0.4471	0.447	0.4483
Max Heel (deg)	34.1189	28.4811	25.3836	27.6595	25.8118	27.546	34.5765	25.762	26.8108	36.537	36.4127	36.0987
St. Immersed at Max Heel	6.979	5.976	5.976	8.318	17.001	17.001	14.997	17.001	17.001	8.318	8.318	8.318
Min Heel (deg)	-34.3514	-28.6486	-25.6402	-27.6539	-26.0426	-29.602	-34.9479	-25.6342	-28.3309	-36.5088	-36.4276	-36.0517
St. Immersed at Min Heel	6.979	5.976	5.976	8.318	17.001	17.001	13.955	17.001	17.001	8.318	8.318	8.318
Max Heel total (deg)	26.4485	27.3589	22.7161	13.4361	7.3539	9.6729	18.6397	8.4298	10.2498	24.5715	25.0635	24.2619
St. Immersed at Max Heel total	17.003	17.003	17.003	17.003	17.5	17.5	17.5	17.5	17.5	17.003	17.003	17.003
Min Heel total (deg)	-26.362	-27.3221	-22.8673	-13.5133	-7.5066	-10.8712	-18.9223	-8.2838	-11.9964	-24.8652	-24.8814	-24.4129
St. Immersed at Min Heel total	17.003	17.003	17.003	17.003	17.5	17.5	17.5	17.5	17.5	17.003	17.003	17.003
Roll Back (deg)	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631
GM (ft)	3.1191	3.1764	2.2596	2.0648	1.4804	2.6277	1.7969	0.3187	1.5276	2.8441	2.9013	3.2222
Righting Arm - Heeling Arm @ Max RA (ft)	3.067	3.178	2.965	2.821	2.355	1.776	2.272	1.017	1.055	2.849	2.876	3.112
Righting Arm at 30deg (ft)	1.9327	2.0767	2.0377	2.0217	1.5687	0.8997	1.3587	0.6517	0.5727	1.7917	1.8007	1.9777
Righting Energy, A1 (ft-rad)	0.396	0.225	0.1135	0.1647	0.0675	0.0126	0.2277	0.0014	-0.0068	0.4406	0.4391	0.4843
Heeling Energy, A2 (ft-rad)	0.0474	0.0487	0.0472	0.0458	0.0367	0.0493	0.0311	0.0278	0.0396	0.0443	0.0451	0.0493
Area Ratio, A1/A2	8.3577	4.6228	2.4061	3.5977	1.8392	0.2547	7.3247	0.05	-0.1714	9.9423	9.7402	9.8282
Righting Arm Ratio	0.1376	0.1323	0.1384	0.1447	0.1703	0.1964	0.1764	0.3062	0.2967	0.1471	0.1458	0.1358
Positive Stability Range (deg)	87.7876	86.6009	84.3091	84.5602	85.5942	72.4018	89.0319	89.5394	72.2636	87.892	87.7164	87.5241
Positive Stability Righting Energy (ft-rad)	3.0947	3.1728	3.009	3.0287	2.5353	1.7442	2.2967	1.0376	0.9764	2.8864	2.9156	3.1621

Table 6. Damage Stability Evaluation Results for CG 47 With Internal 3' Double Hull Using U-Tank Geometry

	15% L Shell Opening Along Ship							Severe Weapons		Bottom Raking		
	St. 0-3	St. 3-6	St. 6-9	St. 9-12	St. 12-15	St. 15-18	St. 18-20	Symetric	Strb. Side	20%	40%	60%
Static Heel (deg)	1.2124	1.855	1.9396	2.278	2.0432	15.0905	-0.0319	-2.1894	14.4773	1.0749	1.0409	1.0282
Maximum Righting Arm (ft)	3.2569	3.4729	3.5499	3.1869	2.4913	1.9943	2.4619	1.3719	1.3629	3.0439	3.1329	3.2729
Heel at Max Righting Arm (deg)	50	50	50	50	55	55	50	50	50	50	50	50
Wind Static Heel (deg)	9.2675	9.3097	8.742	10.2985	14.1344	22.4598	13.6538	21.9508	25.0398	9.7089	9.3193	8.9096
Righting Arm at Wind Static Heel (ft)	0.4482	0.4481	0.4493	0.4457	0.4327	0.3927	0.4343	0.3956	0.3781	0.4473	0.4481	0.449
Max Heel (deg)	34.1189	27.4492	22.0406	25.8036	23.0295	25.6888	34.5769	23.9055	24.7892	36.2446	33.8117	31.1784
St. Immersed at Max Heel	6.979	5.976	5.976	6.979	17.001	17.001	14.997	17.001	17.001	8.318	6.979	6.979
Min Heel (deg)	-34.3514	-27.5207	-22.0662	-25.6471	-23.1571	-27.4561	-34.9482	-23.6112	-26.8229	-36.2437	-33.8705	-31.1079
St. Immersed at Min Heel	6.979	5.976	5.976	6.979	17.001	17.001	13.955	17.001	17.001	6.979	6.979	6.979
Max Heel total (deg)	26.4485	27.4492	22.0406	12.0537	4.775	7.6942	18.6397	6.18	8.253	25.1712	25.2363	22.4024
St. Immersed at Max Heel total	17.003	5.976	5.976	17.003	17.5	17.5	17.5	17.5	17.5	17.003	17.003	17.003
Min Heel total (deg)	-26.362	-27.5207	-22.0662	-12.2443	-4.9271	-8.6835	-18.9223	-6.1364	-9.3212	-24.9871	-25.1241	-22.6718
St. Immersed at Min Heel total	17.003	5.976	5.976	17.003	17.5	17.5	17.5	17.5	17.5	17.003	17.003	17.003
Roll Back (deg)	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631
GM (ft)	3.1191	3.4285	3.4858	2.993	2.019	2.7194	1.7969	0.6281	1.2828	2.8784	3.0274	3.1764
Righting Arm - Heeling Arm @ [illegible]RA (ft)	3.067	3.283	3.36	2.997	2.34	1.843	2.272	1.182	1.173	2.854	2.943	3.083
Righting Arm at 30deg (ft)	1.9327	2.1837	2.4977	2.2907	1.5977	0.9707	1.3587	0.7737	0.6737	1.7987	1.8667	1.9957
Righting Energy, A1 (ft-rad)	0.396	0.2265	0.1367	0.1887	0.0466	0.005	0.2278	-0.0029	-0.0007	0.433	0.3708	0.3186
Heeling Energy, A2 (ft-rad)	0.0474	0.0509	0.0559	0.0487	0.034	0.0472	0.0311	0.0257	0.0382	0.0444	0.0462	0.0485
Area Ratio, A1/A2	8.3577	4.4531	2.4443	3.8728	1.3701	0.1051	7.3277	-0.1124	-0.0186	9.7479	8.0276	6.57
Righting Arm Ratio	0.1376	0.129	0.1266	0.1398	0.1737	0.1969	0.1764	0.2884	0.2774	0.147	0.143	0.1372
Positive Stability Range (deg)	87.7876	87.145	87.0604	86.722	86.9568	73.9095	89.0319	91.1894	74.5227	87.9251	87.9591	87.9718
Positive Stability Righting Energy (ft-rad)	3.0947	3.3074	3.5379	3.329	2.5903	1.8052	2.2968	1.1725	1.0876	2.8942	3.0172	3.2646

Table 7. Damage Stability Evaluation Results for CG 47 With Internal 3' Double Hull Using J-Tank Geometry

	15% L Shell Opening Along Ship							Severe Weapons		Bottom Raking		
	St. 0-3	St. 3-6	St. 6-9	St. 9-12	St. 12-15	St. 15-18	St. 18-20	Symetric	Strb. Side	20%	40%	60%
Static Heel (deg)	1.2124	4.7392	13.0142	16.3649	19.0961	19.1982	-0.0319	-2.1894	20.2	1.5988	7.4636	18.848
Maximum Righting Arm (ft)	3.2569	3.3179	3.0659	2.7173	2.1583	1.8739	2.4619	1.3719	1.2719	3.0179	2.8813	2.6813
Heel at Max Righting Arm (deg)	50	50	50	55	55	50	50	50	50	50	55	55
Wind Static Heel (deg)	9.2675	12.0416	17.9393	20.6108	24.0326	25.1052	13.6538	21.9599	27.4209	10.2128	14.9682	23.6946
Righting Arm at Wind Static Heel (ft)	0.4482	0.4398	0.4162	0.4032	0.3838	0.3776	0.4343	0.3956	0.3624	0.446	0.4298	0.3857
Max Heel (deg)	34.1189	28.1669	24.1696	27.0152	25.1058	26.8187	34.5769	23.896	25.9772	36.3204	34.6163	32.8304
St. Immersed at Max Heel	6.979	5.976	5.976	6.979	17.001	17.001	14.997	17.001	17.001	8.318	6.979	6.979
Min Heel (deg)	-34.3514	-28.9548	-25.8919	-28.1183	-26.9659	-29.5442	-34.9482	-23.596	-28.3649	-36.4601	-35.8376	-35.1812
St. Immersed at Min Heel	6.979	5.976	5.976	8.318	17.001	17.001	13.955	17.001	17.001	8.318	6.979	6.979
Max Heel total (deg)	26.4485	27.3983	22.6459	13.7352	7.6981	8.9889	18.6397	6.1724	9.5228	25.1337	25.1802	23.3666
St. Immersed at Max Heel total	17.003	17.003	17.003	17.003	17.5	17.5	17.5	17.5	17.5	17.003	17.003	17.003
Min Heel total (deg)	-26.362	-27.2429	-22.793	-14.2691	-8.5538	-10.5108	-18.9223	-6.1367	-11.6964	-24.9049	-24.8704	-24.0908
St. Immersed at Min Heel total	17.003	17.003	17.003	17.003	17.5	17.5	17.5	17.5	17.5	17.003	17.003	17.003
Roll Back (deg)	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631
GM (ft)	3.1191	3.3368	4.3195	5.3435	3.4872	2.7881	1.7969	0.6281	2.5745	2.867	3.112	4.1289
Righting Arm - Heeling Arm @ Max RA (ft)	3.067	3.128	2.876	2.566	2.007	1.684	2.272	1.182	1.082	2.828	2.73	2.53
Righting Arm at 30deg (ft)	1.9327	1.9667	1.7347	1.4547	0.9567	0.7937	1.3587	0.7727	0.5187	1.7667	1.5167	0.9497
Righting Energy, A1 (ft-rad)	0.396	0.1828	0.0332	0.0441	-0.0016	-0.0257	0.2278	-0.0028	-0.0001	0.4218	0.2593	0.0724
Heeling Energy, A2 (ft-rad)	0.0474	0.0521	0.0701	0.0661	0.0645	0.0568	0.0311	0.0257	0.0458	0.0454	0.051	0.068
Area Ratio, A1/A2	8.3577	3.5085	0.4742	0.667	-0.025	-0.4526	7.3277	-0.1099	-0.0029	9.2864	5.0891	1.0641
Righting Arm Ratio	0.1376	0.1325	0.1358	0.1484	0.1778	0.2015	0.1764	0.2884	0.2849	0.1478	0.1492	0.1439
Positive Stability Range (deg)	87.7876	84.2608	75.9858	72.6351	69.9039	69.8018	89.0319	91.1894	68.8	87.4012	81.5364	70.152
Positive Stability Righting Energy (ft-rad)	3.0947	3.0988	2.845	2.6071	2.0363	1.6733	2.2968	1.172	0.971	2.8601	2.6697	2.3714

Table 8. Damage Stability Evaluation Results for CG 47 With Internal 3' Double Hull Using Wing Tank Geometry

	15% L Shell Opening Along Ship							Severe Weapons		Bottom Raking		
	St. 0-3	St. 3-6	St. 6-9	St. 9-12	St. 12-15	St. 15-18	St. 18-20	Symetric	Strb. Side	20%	40%	60%
Static Heel (deg)	1.2124	1.8445	3.6072	8.5152	9.0618	15.3933	-0.0319	-2.1894	14.9727	1.0749	1.1082	5.6695
Maximum Righting Arm (ft)	3.2569	3.4729	3.5499	3.1859	2.4913	1.9923	2.4619	1.3719	1.3609	3.0439	3.1329	3.2729
Heel at Max Righting Arm (deg)	50	50	50	50	55	55	50	50	50	50	50	50
Wind Static Heel (deg)	9.2675	9.2959	9.854	13.8075	16.8217	22.5232	13.6538	21.9508	25.0247	9.7089	9.339	11.8316
Righting Arm at Wind Static Heel (ft)	0.4482	0.4482	0.447	0.4338	0.4213	0.3924	0.4343	0.3956	0.3782	0.4473	0.4481	0.4405
Max Heel (deg)	34.1189	27.4492	22.0924	25.8747	23.2716	25.7088	34.5769	23.9055	25.0725	36.2446	33.8095	31.1455
St. Immersed at Max Heel	6.979	5.976	5.976	6.979	17.001	17.001	14.997	17.001	17.001	8.318	6.979	6.979
Min Heel (deg)	-34.3514	-27.5473	-22.6678	-26.8262	-24.6464	-28.1292	-34.9482	-23.6112	-27.7655	-36.2436	-34.0098	-32.1512
St. Immersed at Min Heel	6.979	5.976	5.976	6.979	17.001	17.001	13.955	17.001	17.001	6.979	6.979	6.979
Max Heel total (deg)	26.4485	27.4492	22.0924	12.5111	5.6413	7.7593	18.6397	6.18	8.2289	25.1712	25.2499	22.474
St. Immersed at Max Heel total	17.003	5.976	5.976	17.003	17.5	17.5	17.5	17.5	17.5	17.003	17.003	17.003
Min Heel total (deg)	-26.362	-27.5362	-22.516	-13.0831	-6.0284	-9.0582	-18.9223	-6.1364	-9.5678	-24.9871	-25.1076	-23.0728
St. Immersed at Min Heel total	17.003	17.003	17.003	17.003	17.5	17.5	17.5	17.5	17.5	17.003	17.003	17.003
Roll Back (deg)	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631
GM (ft)	3.1191	3.417	3.6691	3.811	2.3671	2.8111	1.7969	0.6281	1.4776	2.8784	3.0503	4.0058
Righting Arm - Heeling Arm @ Max RA (ft)	3.067	3.283	3.36	2.996	2.34	1.841	2.272	1.182	1.171	2.854	2.943	3.083
Righting Arm at 30deg (ft)	1.9327	2.1837	2.4927	2.2367	1.5687	0.9707	1.3587	0.7737	0.6747	1.7987	1.8667	1.9917
Righting Energy, A1 (ft-rad)	0.396	0.2265	0.1278	0.1379	0.0296	0.0049	0.2278	-0.0029	-0.0144	0.433	0.3707	0.2836
Heeling Energy, A2 (ft-rad)	0.0474	0.0509	0.0605	0.0674	0.0486	0.0486	0.0311	0.0257	0.0389	0.0444	0.0464	0.0609
Area Ratio, A1/A2	8.3577	4.4486	2.1124	2.0461	0.6088	0.1007	7.3277	-0.1124	-0.3712	9.7479	7.9859	4.6565
Righting Arm Ratio	0.1376	0.129	0.1259	0.1362	0.1691	0.1969	0.1764	0.2884	0.2779	0.147	0.143	0.1346
Positive Stability Range (deg)	87.7876	87.1555	85.3928	76.4848	79.9382	73.6067	89.0319	91.1894	74.0273	87.9251	87.8918	83.3305
Positive Stability Righting Energy (ft-rad)	3.0947	3.3076	3.5122	3.0748	2.5274	1.803	2.2968	1.1725	1.0873	2.8942	3.0167	3.2018

Table 9. Damage Stability Evaluation Results for CG 47 With Internal 3' Double Hull Using Segmented Tank Geometry

	15% L Shell Opening Along Ship							Severe Weapons		Bottom Raking		
	St. 0-3	St. 3-6	St. 6-9	St. 9-12	St. 12-15	St. 15-18	St. 18-20	Symetric	Strb. Side	20%	40%	60%
Static Heel (deg)	1.2124	6.5789	15.8216	18.0269	20.2466	20.0792	-0.0319	-2.0323	23.1053	1.5988	7.3275	12.6876
Maximum Righting Arm (ft)	3.2569	3.3329	3.1579	2.9803	2.4893	2.0023	2.4619	1.3969	1.1989	3.0189	2.9543	3.2303
Heel at Max Righting Arm (deg)	50	50	50	55	55	55	50	50	50	50	55	55
Wind Static Heel (deg)	9.2675	13.4051	19.6224	21.9129	24.5215	25.0669	13.6538	20.5464	29.1011	10.2128	14.7774	18.0424
Righting Arm at Wind Static Heel (ft)	0.4482	0.4351	0.4084	0.3958	0.381	0.3779	0.4343	0.4036	0.3513	0.446	0.4305	0.4157
Max Heel (deg)	34.1189	27.6479	23.0056	30.0628	29.6535	25.8915	34.5769	21.1347	25.0097	36.3202	34.7087	33.7629
St. Immersed at Max Heel	6.979	5.976	5.976	6.979	17.001	17.001	14.997	17.001	17.001	8.318	6.979	6.979
Min Heel (deg)	-34.3514	-28.49	-24.7048	-30.8948	-31.3429	-28.6064	-34.9482	-20.9244	-27.6546	-36.4601	-35.8376	-34.9991
St. Immersed at Min Heel	6.979	5.976	5.976	6.979	14.997	17.001	13.955	17.001	17.001	8.318	6.979	6.979
Max Heel total (deg)	26.4485	27.4297	22.6102	18.4879	12.5007	7.7946	18.6397	2.7181	8.0661	25.1337	25.1871	24.112
St. Immersed at Max Heel total	17.003	17.003	17.003	17.003	17.5	17.5	17.5	20	17.5	17.003	17.003	17.003
Min Heel total (deg)	-26.362	-27.3434	-22.681	-18.9298	-13.6295	-9.2887	-18.9223	-2.6424	-9.7539	-24.9049	-24.8704	-24.1529
St. Immersed at Min Heel total	17.003	17.003	17.003	17.003	17.5	17.5	17.5	20	17.5	17.003	17.003	17.003
Roll Back (deg)	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631
GM (ft)	3.1191	3.513	6.1571	5.3435	5.107	4.3278	1.7969	0.8458	2.712	2.867	3.1463	4.2049
Righting Arm - Heeling Arm @ Max RA (ft)	3.067	3.143	2.968	2.829	2.338	1.851	2.272	1.207	1.009	2.829	2.803	3.079
Righting Arm at 30deg (ft)	1.9327	1.9487	1.7347	1.3737	0.9657	0.8347	1.3587	0.8497	0.4087	1.7667	1.5537	1.5337
Righting Energy, A1 (ft-rad)	0.396	0.1543	0.0179	0.0657	0.0254	-0.0245	0.2278	-0.009	-0.008	0.4218	0.271	0.2122
Heeling Energy, A2 (ft-rad)	0.0474	0.055	0.058	0.059	0.0653	0.0644	0.0311	0.0257	0.0523	0.0454	0.0504	0.0665
Area Ratio, A1/A2	8.3577	2.808	0.3086	1.1137	0.3894	-0.3807	7.3277	-0.3487	-0.1537	9.2862	5.375	3.1924
Righting Arm Ratio	0.1376	0.1306	0.1293	0.1328	0.1531	0.1887	0.1764	0.2889	0.2931	0.1477	0.1457	0.1287
Positive Stability Range (deg)	87.7876	82.4211	73.1784	70.9731	68.7534	68.9208	89.0319	91.0323	65.8947	87.4012	81.6725	76.3124
Positive Stability Righting Energy (ft-rad)	3.0947	3.0981	2.9548	2.7597	2.2856	1.7849	2.2968	1.2664	0.9217	2.8606	2.7437	2.9919

Table 10. Damage Stability Evaluation Results for CG 47 With Internal 6' Double Hull Using U-Tank Geometry

	15% L Shell Opening Along Ship							Severe Weapons		Bottom Raking		
	St. 0-3	St. 3-6	St. 6-9	St. 9-12	St. 12-15	St. 15-18	St. 18-20	Symetric	Strb. Side	20%	40%	60%
Static Heel (deg)	1.2124	1.5007	1.0556	1.6062	1.5706	13.7044	-0.0319	-2.6095	12.7703	1.0269	0.9246	0.8095
Maximum Righting Arm (ft)	3.2569	3.5259	3.6879	3.1579	2.3903	1.9823	2.4619	1.4256	1.4019	3.0469	3.2149	3.4409
Heel at Max Righting Arm (deg)	50	50	50	50	55	55	50	45	50	50	50	50
Wind Static Heel (deg)	9.2675	8.6379	6.9649	8.6567	13.7446	21.7559	13.6538	20.5511	23.8156	9.6197	8.7861	7.7077
Righting Arm at Wind Static Heel (ft)	0.4482	0.4495	0.453	0.4495	0.434	0.3967	0.4343	0.4036	0.385	0.4475	0.4492	0.4515
Max Heel (deg)	34.1189	26.6791	19.5649	24.2966	20.7487	23.8941	34.5769	21.9448	23.4255	35.9938	31.2156	25.2941
St. Immersed at Max Heel	6.979	5.976	5.011	6.979	17.001	17.001	14.997	17.001	17.001	6.979	5.976	5.976
Min Heel (deg)	-34.3514	-26.6854	-19.6079	-24.341	-20.878	-26.013	-34.9482	-21.7168	-24.9885	-35.9632	-31.0333	-25.1447
St. Immersed at Min Heel	6.979	5.976	5.011	6.979	17.001	17.001	13.955	17.001	17.001	6.979	5.976	5.976
Max Heel total (deg)	26.4485	26.6791	19.5649	11.1714	2.7975	5.9934	18.6397	3.8347	6.6025	25.0504	25.6117	20.2877
St. Immersed at Max Heel total	17.003	5.976	5.011	17.003	17.5	17.5	17.5	18.003	17.5	17.003	17.003	17.003
Min Heel total (deg)	-26.362	-26.6854	-19.6079	-11.4798	-3.0105	-6.8158	-18.9223	-3.8236	-7.4216	-25.0622	-25.3536	-20.042
St. Immersed at Min Heel total	17.003	5.976	5.011	17.003	17.5	17.5	17.5	18.003	17.5	17.003	17.003	17.003
Roll Back (deg)	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631
GM (ft)	3.1191	3.5889	4.2879	3.5316	2.2253	1.8443	1.7969	- 0.8343	1.3286	2.9013	3.2222	3.6806
Righting Arm - Heeling Arm @ Max RA (ft)	3.067	3.336	3.498	2.968	2.239	1.831	2.272	1.195	1.212	2.857	3.025	3.251
Righting Arm at 30deg (ft)	1.9327	2.2477	2.7147	2.3647	1.5357	1.0187	1.3587	0.8557	0.7437	1.8097	1.9597	2.2607
Righting Energy, A1 (ft-rad)	0.396	0.223	0.121	0.1818	0.0247	-0.0066	0.2278	-0.0101	-0.0005	0.4273	0.314	0.2061
Heeling Energy, A2 (ft-rad)	0.0474	0.0532	0.0645	0.054	0.0329	0.0458	0.0311	0.025	0.037	0.0446	0.0485	0.0553
Area Ratio, A1/A2	8.3577	4.1895	1.8768	3.3675	0.7485	-0.1438	7.3277	-0.4059	-0.0125	9.5827	6.4697	3.726
Righting Arm Ratio	0.1376	0.1275	0.1228	0.1423	0.1816	0.2001	0.1764	0.2831	0.2747	0.1469	0.1397	0.1312
Positive Stability Range (deg)	87.7876	87.4993	87.9444	87.3938	87.4294	75.2956	89.0319	91.6095	76.2297	87.9731	88.0754	88.1905
Positive Stability Righting Energy (ft-rad)	3.0947	3.3789	3.7593	3.3862	2.5371	1.8301	2.2968	1.2733	1.1724	2.899	3.1309	3.5849

Table 11. Damage Stability Evaluation Results for CG 47 With Internal 6' Double Hull Using J-Tank Geometry

	15% L Shell Opening Along Ship							Severe Weapons		Bottom Raking		
	St. 0-3	St. 3-6	St. 6-9	St. 9-12	St. 12-15	St. 15-18	St. 18-20	Symetric	Strb. Side	20%	40%	60%
Static Heel (deg)	1.2124	6.4463	18.0341	22.4262	25.8314	21.0872	-0.0319	-2.6095	22.0272	1.9985	12.0544	28.3593
Maximum Righting Arm (ft)	3.2569	3.2389	2.7983	2.336	1.8269	1.8323	2.4619	1.4246	1.2459	2.9959	2.7493	2.3409
Heel at Max Righting Arm (deg)	50	50	55	60	65	55	50	45	50	50	55	65
Wind Static Heel (deg)	9.2675	13.387	22.0041	25.8266	29.445	26.2463	13.6538	20.5511	28.3244	10.5254	18.5805	31.4538
Righting Arm at Wind Static Heel (ft)	0.4482	0.4352	0.3953	0.3729	0.3491	0.3701	0.4343	0.4036	0.3565	0.4449	0.4132	0.3349
Max Heel (deg)	34.1189	28.1028	23.8159	26.8486	25.1423	25.6377	34.5769	21.9532	25.4686	36.1801	33.06	29.6555
St. Immersed at Max Heel	6.979	5.976	5.976	6.979	17.001	17.001	14.997	17.001	17.001	8.318	6.979	5.976
Min Heel (deg)	-34.3514	-29.357	-26.8158	-28.9421	-28.1122	-29.2727	-34.9482	-21.7224	-28.6237	-36.4211	-35.2098	-33.742
St. Immersed at Min Heel	6.979	5.976	5.976	8.318	17.001	17.001	13.955	17.001	17.001	8.318	6.979	6.979
Max Heel total (deg)	26.4485	27.32	22.6363	14.2139	8.4923	8.6243	18.6397	3.8486	9.0346	25.1743	25.3627	22.0651
St. Immersed at Max Heel total	17.003	17.003	17.003	17.003	17.5	17.5	17.5	18.003	17.5	17.003	17.003	17.003
Min Heel total (deg)	-26.362	-27.1641	-22.8956	-15.1247	-9.6823	-10.4381	-18.9223	-3.8301	-11.0809	-24.9376	-24.9866	-23.269
St. Immersed at Min Heel total	17.003	17.003	17.003	17.003	17.5	17.5	17.5	18.003	17.5	17.003	17.003	17.003
Roll Back (deg)	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631
GM (ft)	3.1191	3.4786	5.2175	6.0925	5.5349	3.8465	1.7969	0.8343	2.7693	2.867	3.4371	5.8214
Righting Arm - Heeling Arm @ Max RA (ft)	3.067	3.049	2.647	2.221	1.745	1.681	2.272	1.194	1.056	2.806	2.598	2.259
Righting Arm at 30deg (ft)	1.9327	1.8587	1.3237	0.8737	0.4027	0.6937	1.3587	0.8547	0.4637	1.7497	1.2927	0.1667
Righting Energy, A1 (ft-rad)	0.396	0.1562	-0.0067	-0.0223	-0.0151	-0.0012	0.2278	-0.0102	-0.0029	0.4078	0.1511	-0.004
Heeling Energy, A2 (ft-rad)	0.0474	0.0541	0.0604	0.0436	0.0497	0.0611	0.0311	0.0251	0.0509	0.0458	0.0554	0.0338
Area Ratio, A1/A2	8.3577	2.8844	-0.1108	-0.5106	-0.303	-0.0202	7.3277	-0.4052	-0.057	8.9104	2.728	-0.1194
Righting Arm Ratio	0.1376	0.1344	0.1413	0.1596	0.1911	0.202	0.1764	0.2833	0.2861	0.1485	0.1503	0.143
Positive Stability Range (deg)	87.7876	82.5537	70.9659	66.5738	63.1686	67.9128	89.0319	91.6095	66.9728	87.0015	76.9456	60.6407
Positive Stability Righting Energy (ft-rad)	3.0947	2.998	2.5372	2.1624	1.6365	1.6007	2.2968	1.2724	0.9513	2.835	2.489	1.9588

Table 12. Damage Stability Evaluation Results for CG 47 With Internal 6' Double Hull Using Wing Tank Geometry

	15% L Shell Opening Along Ship							Severe Weapons		Bottom Raking		
	St. 0-3	St. 3-6	St. 6-9	St. 9-12	St. 12-15	St. 15-18	St. 18-20	Symetric	Strb. Side	20%	40%	60%
Static Heel (deg)	1.2124	1.5277	5.7435	12.8791	15.5965	16.4777	-0.0319	-2.6095	16.7163	1.0269	1.8801	11.404
Maximum Righting Arm (ft)	3.2569	3.5259	3.6879	3.1549	2.3913	1.9813	2.4619	1.4256	1.4019	3.0469	3.2149	3.4399
Heel at Max Righting Arm (deg)	50	50	50	50	55	55	50	45	50	50	50	50
Wind Static Heel (deg)	9.2675	8.6421	10.6912	16.9071	20.8164	22.8049	13.6538	20.5511	24.976	9.6197	9.3599	15.8438
Righting Arm at Wind Static Heel (ft)	0.4482	0.4495	0.4443	0.4209	0.4021	0.3908	0.4343	0.4036	0.3785	0.4475	0.448	0.4258
Max Heel (deg)	34.1189	26.677	20.0881	24.9018	22.0031	24.0368	34.5769	21.9358	23.7538	35.9935	31.2184	25.7226
St. Immersed at Max Heel	6.979	5.976	5.011	6.979	17.001	17.001	14.997	17.001	17.001	6.979	5.976	5.976
Min Heel (deg)	-34.3514	-26.9298	-21.6256	-26.8095	-24.5863	-27.3651	-34.9482	-21.7101	-27.0083	-35.9934	-31.8842	-28.2365
St. Immersed at Min Heel	6.979	5.976	5.976	6.979	17.001	17.001	13.955	17.001	17.001	6.979	5.976	5.976
Max Heel total (deg)	26.4485	26.677	20.0881	12.3164	5.3128	6.763	18.6397	3.8347	7.2128	25.0547	25.6561	20.7748
St. Immersed at Max Heel total	17.003	5.976	5.011	17.003	18.003	17.5	17.5	18.003	17.5	17.003	17.003	17.003
Min Heel total (deg)	-26.362	-26.9298	-21.6256	-13.3322	-5.9694	-8.0461	-18.9223	-3.8107	-8.708	-25.0651	-25.287	-21.8361
St. Immersed at Min Heel total	17.003	5.976	5.976	17.003	17.5	17.5	17.5	18.003	17.5	17.003	17.003	17.003
Roll Back (deg)	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631
GM (ft)	3.1191	3.6004	5.0715	5.5571	4.2549	3.0746	1.7969	0.8343	2.1464	2.9013	3.3826	5.3966
Righting Arm - Heeling Arm @ Max RA (ft)	3.067	3.336	3.498	2.965	2.24	1.83	2.272	1.195	1.212	2.857	3.025	3.25
Righting Arm at 30deg (ft)	1.9327	2.2477	2.6117	2.0417	1.3057	0.9897	1.3587	0.8557	0.7087	1.8097	1.9577	2.0317
Righting Energy, A1 (ft-rad)	0.396	0.2232	0.0784	0.0628	-0.0177	-0.0026	0.2278	-0.0101	-0.003	0.4272	0.3088	0.0952
Heeling Energy, A2 (ft-rad)	0.0474	0.0534	0.0755	0.0637	0.0645	0.0537	0.0311	0.025	0.0447	0.0446	0.0508	0.0691
Area Ratio, A1/A2	8.3577	4.1789	1.0387	0.9867	-0.275	-0.0479	7.3277	-0.4054	-0.0673	9.5804	6.0843	1.3778
Righting Arm Ratio	0.1376	0.1275	0.1205	0.1334	0.1681	0.1972	0.1764	0.2831	0.27	0.1469	0.1394	0.1238
Positive Stability Range (deg)	87.7876	87.4723	83.2565	76.1209	73.4035	72.5223	89.0319	91.6095	72.2837	87.9731	87.1199	77.596
Positive Stability Righting Energy (ft-rad)	3.0947	3.379	3.6354	3.107	2.3545	1.808	2.2968	1.2733	1.1489	2.899	3.1175	3.3433

Table 13. Damage Stability Evaluation Results for CG 47 With Internal 6' Double Hull Using Segmented Tank Geometry

	15% L Shell Opening Along Ship							Severe Weapons		Bottom Raking		
	St. 0-3	St. 3-6	St. 6-9	St. 9-12	St. 12-15	St. 15-18	St. 18-20	Symetric	Strb. Side	20%	40%	60%
Static Heel (deg)	1.2124	9.4575	19.2396	21.3744	23.1687	20.6567	-0.0319	-3.6828	24.877	1.9985	10.6269	15.4799
Maximum Righting Arm (ft)	3.2569	3.3419	3.2333	3.105	2.632	2.0693	2.4619	1.5606	1.1839	3.0119	3.0343	3.5343
Heel at Max Righting Arm (deg)	50	50	55	60	60	55	50	45	50	50	55	55
Wind Static Heel (deg)	9.2675	15.4327	22.0656	24.2481	26.2895	25.1391	13.6538	17.3156	29.8912	10.5254	16.9591	19.71
Righting Arm at Wind Static Heel (ft)	0.4482	0.4277	0.395	0.3826	0.3698	0.3774	0.4343	0.4191	0.3462	0.4449	0.4207	0.408
Max Heel (deg)	34.1189	27.1524	22.039	29.1098	27.7979	24.7694	34.5769	17.0639	23.6468	36.1805	33.5772	32.0723
St. Immersed at Max Heel	6.979	5.976	5.976	6.979	17.001	17.001	14.997	17.001	17.001	8.318	6.979	6.979
Min Heel (deg)	-34.3514	-28.455	-24.4738	-30.3579	-29.9836	-27.5264	-34.9482	-16.8122	-27.2399	-36.4211	-35.2098	-33.4596
St. Immersed at Min Heel	6.979	5.976	5.976	6.979	17.001	17.001	13.955	17.001	17.001	8.318	6.979	6.979
Max Heel total (deg)	26.4485	27.1524	22.039	17.4996	10.7679	7.0194	18.6397	8.8548	7.2053	25.1759	25.3769	23.5852
St. Immersed at Max Heel total	17.003	5.976	5.976	17.003	17.5	17.5	17.5	17.002	17.5	17.003	17.003	17.003
Min Heel total (deg)	-26.362	-27.3861	-22.7795	-18.2466	-12.1368	-8.248	-18.9223	4.3219	-8.7635	-24.9384	-24.9895	-23.4762
St. Immersed at Min Heel total	17.003	17.003	17.003	17.003	17.5	17.5	17.5	20	17.5	17.003	17.003	17.003
Roll Back (deg)	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631	9.7631
GM (ft)	3.1191	3.7766	7.2343	7.628	6.3102	4.7976	1.7969	0.7312	3.1131	2.867	3.6777	5.5269
Righting Arm - Heeling Arm @ Max RA (ft)	3.067	3.152	3.082	2.99	2.517	1.918	2.272	1.33	0.994	2.822	2.883	3.383
Righting Arm at 30deg (ft)	1.9327	1.8857	1.5487	1.2217	0.8537	0.8567	1.3587	1.0367	0.3537	1.7487	1.5007	1.5837
Righting Energy, A1 (ft-rad)	0.396	0.1186	0	0.032	-0.0188	-0.0016	0.2278	0	-0.0198	0.4078	0.2105	0.164
Heeling Energy, A2 (ft-rad)	0.0474	0.0621	0.0304	0.0303	0.0383	0.0663	0.0311	0.0272	0.0599	0.0458	0.0576	0.0653
Area Ratio, A1/A2	8.3577	1.9084	-0.001	1.0574	-0.4918	-0.0242	7.3277	-0.0012	-0.3308	8.9113	3.6516	2.5115
Righting Arm Ratio	0.1376	0.128	0.1222	0.1232	0.1405	0.1824	0.1764	0.2685	0.2924	0.1477	0.1386	0.1155
Positive Stability Range (deg)	87.7876	79.5425	69.7604	67.6256	65.8313	68.3433	89.0319	92.6828	64.123	87.0015	78.3731	73.5201
Positive Stability Righting Energy (ft-rad)	3.0947	3.0919	3.0093	2.8872	2.4409	1.8691	2.2968	1.5179	0.95	2.8478	2.7936	3.3058

Table 14. Damage Stability Evaluation Results for CG 47 With External 3' Double Hull Using U-Tank Geometry

	15% L Shell Opening Along Ship							Severe Weapons		Bottom Raking		
	St. 0-3	St. 3-6	St. 6-9	St. 9-12	St. 12-15	St. 15-18	St. 18-20	Symetric	Strb. Side	20%	40%	60%
Static Heel (deg)	1.2153	2.1209	2.7347	3.0895	3.3416	14.2255	0.2394	0.1845	14.1072	1.1308	1.2007	1.3131
Maximum Righting Arm (ft)	2.9576	3.0706	3.0216	2.6056	1.9966	1.6686	2.2986	1.0956	1.0746	2.8036	2.8966	3.1606
Heel at Max Righting Arm (deg)	45	45	45	45	45	45	45	45	45	45	45	45
Wind Static Heel (deg)	9.9896	10.3489	9.7982	11.1336	14.4258	21.9476	13.6731	22.1072	24.5424	10.3852	10.0223	9.1071
Righting Arm at Wind Static Heel (ft)	0.4702	0.4689	0.4706	0.4661	0.4544	0.4164	0.457	0.4155	0.4009	0.4688	0.4701	0.4721
Max Heel (deg)	31.5136	24.5037	18.4526	22.4722	20.0702	24.915	31.856	23.5452	24.4421	33.2682	30.9124	27.9724
St. Immersed at Max Heel	6.979	5.976	5.976	6.979	14.997	14.997	14.997	14.997	14.997	8.318	6.979	6.979
Min Heel (deg)	-31.6798	-24.5928	-18.477	-22.618	-19.9386	-26.1776	-32.1819	-23.6597	-25.7264	-33.3422	-30.939	-28.0527
St. Immersed at Min Heel	6.979	5.976	5.976	6.979	14.997	14.997	13.955	14.997	14.997	8.318	6.979	6.979
Max Heel total (deg)	26.5407	24.5037	18.4526	10.5653	1.5679	7.3051	18.9885	5.7353	7.9197	25.1022	25.4496	21.99
St. Immersed at Max Heel total	17.003	5.976	5.976	17.003	17.5	17.5	17.5	17.5	17.5	17.003	17.003	17.003
Min Heel total (deg)	-26.2208	-24.5928	-18.477	-10.4688	-1.6051	-8.5689	-19.1667	-5.7375	-8.9699	-24.8225	-25.1334	-21.9865
St. Immersed at Min Heel total	17.003	5.976	5.976	17.003	17.5	17.5	17.5	17.5	17.5	17.003	17.003	17.003
Roll Back (deg)	9.1216	9.1216	9.1216	9.1216	9.1216	9.1216	9.1216	9.1216	9.1216	9.1216	9.1216	9.1216
GM (ft)	2.9701	3.1878	3.3941	2.6149	1.4231	1.9016	1.6752	0.621	1.3286	2.7868	2.9586	3.3597
Righting Arm - Heeling Arm @ Max RA (ft)	2.715	2.828	2.779	2.363	1.754	1.426	2.056	0.853	0.832	2.561	2.654	2.918
Righting Arm at 30deg (ft)	1.9657	2.1787	2.3597	2.1617	1.6067	1.0457	1.4747	0.7957	0.7157	1.8487	1.9227	2.1867
Righting Energy, A1 (ft-rad)	0.3036	0.1376	0.0604	0.1036	0.0187	-0.0058	0.1839	-0.0022	-0.0002	0.3311	0.2778	0.2469
Heeling Energy, A2 (ft-rad)	0.0424	0.0446	0.0514	0.0457	0.0372	0.0433	0.0287	0.0262	0.0356	0.0401	0.0422	0.0437
Area Ratio, A1/A2	7.1585	3.0868	1.1757	2.2684	0.503	-0.134	6.4042	-0.0825	-0.0054	8.2604	6.5861	5.653
Righting Arm Ratio	0.159	0.1527	0.1557	0.1789	0.2276	0.2496	0.1988	0.3792	0.3731	0.1672	0.1623	0.1494
Positive Stability Range (deg)	87.7847	86.8791	86.2653	85.9105	85.6584	71.1281	86.8645	70.7266	56.8057	87.8692	87.7993	87.6869
Positive Stability Righting Energy (ft-rad)	2.5491	2.6863	2.7991	2.5754	1.9256	1.2006	1.8189	0.6851	0.6144	2.4013	2.5471	2.9672

Table 15. Damage Stability Evaluation Results for CG 47 With External 3' Double Hull Using J-Tank Geometry

	15% L Shell Opening Along Ship							Severe Weapons		Bottom Raking		
	St. 0-3	St. 3-6	St. 6-9	St. 9-12	St. 12-15	St. 15-18	St. 18-20	Symetric	Strb. Side	20%	40%	60%
Static Heel (deg)	1.2153	5.3364	14.4843	17.2042	19.2639	18.4186	0.2394	0.1845	19.6114	1.6377	8.1428	18.6877
Maximum Righting Arm (ft)	2.9576	2.9066	2.4759	2.0639	1.5729	1.5666	2.2986	1.0946	0.9407	2.7776	2.6209	2.4559
Heel at Max Righting Arm (deg)	45	45	50	50	50	45	45	45	40	45	50	50
Wind Static Heel (deg)	9.9896	13.1367	19.2665	21.3929	23.8886	24.5113	13.6731	22.1158	27.0419	10.8296	15.7894	23.3234
Righting Arm at Wind Static Heel (ft)	0.4702	0.459	0.4316	0.4198	0.4048	0.4011	0.457	0.4154	0.3841	0.4672	0.4485	0.4082
Max Heel (deg)	31.5136	25.3617	20.6894	23.8314	22.0731	25.7084	31.856	23.516	25.2344	33.3405	31.7526	29.7471
St. Immersed at Max Heel	6.979	5.976	5.976	6.979	14.997	14.997	14.997	17.001	14.997	8.318	6.979	6.979
Min Heel (deg)	-31.6798	-25.9814	-22.0613	-24.8097	-23.1807	-27.756	-32.1819	-23.2654	-26.9126	-33.5086	-32.8242	-31.7725
St. Immersed at Min Heel	6.979	5.976	5.976	8.318	14.997	14.997	13.955	17.001	14.997	8.318	6.979	6.979
Max Heel total (deg)	26.5407	25.3617	20.6894	12.2377	5.2297	8.7943	18.9885	5.5753	9.1003	25.0508	25.2575	22.8679
St. Immersed at Max Heel total	17.003	5.976	5.976	17.003	18.003	17.5	17.5	18.003	17.5	17.003	17.003	17.003
Min Heel total (deg)	-26.2208	-25.9814	-22.0613	-12.9892	-5.5155	-10.1578	-19.1667	-5.5644	-11.322	-24.7579	-24.8556	-23.6209
St. Immersed at Min Heel total	17.003	5.976	5.976	17.003	17.5	17.5	17.5	18.003	17.5	17.003	17.003	17.003
Roll Back (deg)	9.1216	9.1216	9.1216	9.1216	9.1216	9.1216	9.1216	9.1216	9.1216	9.1216	9.1216	9.1216
GM (ft)	2.9701	3.2036	4.4111	5.4925	4.0487	2.9715	1.6752	0.621	2.0662	2.7638	3.0776	4.5414
Righting Arm - Heeling Arm @ Max RA (ft)	2.715	2.664	2.276	1.864	1.373	1.324	2.056	0.852	0.656	2.535	2.421	2.256
Righting Arm at 30deg (ft)	1.9657	1.9667	1.6017	1.3427	0.9607	0.8747	1.4747	0.7937	0.5657	1.8187	1.5537	1.0857
Righting Energy, A1 (ft-rad)	0.3036	0.1041	0.0021	-0.0165	-0.0043	0.0021	0.1839	-0.0021	-0.001	0.3213	0.181	0.0343
Heeling Energy, A2 (ft-rad)	0.0424	0.0442	0.0648	0.0669	0.062	0.0514	0.0287	0.0262	0.0418	0.04	0.0466	0.0642
Area Ratio, A1/A2	7.1585	2.3543	0.0328	-0.247	-0.0686	0.0404	6.4042	-0.0797	-0.0236	8.031	3.8838	0.535
Righting Arm Ratio	0.159	0.1579	0.1743	0.2034	0.2574	0.256	0.1988	0.3795	0.4083	0.1682	0.1711	0.1662
Positive Stability Range (deg)	87.7847	83.6636	74.5157	71.7958	69.7361	66.4631	86.8645	70.7333	50.1174	87.3623	80.8572	70.3123
Positive Stability Righting Energy (ft-rad)	2.5491	2.4771	2.0947	1.8382	1.3497	1.0803	1.8189	0.6831	0.5051	2.3697	2.1855	2.0279

Table 16. Damage Stability Evaluation Results for CG 47 With External 3' Double Hull Using Wing Tank Geometry

	15% L Shell Opening Along Ship							Severe Weapons		Bottom Raking		
	St. 0-3	St. 3-6	St. 6-9	St. 9-12	St. 12-15	St. 15-18	St. 18-20	Symetric	Strb. Side	20%	40%	60%
Static Heel (deg)	1.2153	2.1209	4.4025	9.2369	10.1453	14.6655	0.2394	0.188	14.8039	1.1308	1.2732	5.5776
Maximum Righting Arm (ft)	2.9576	3.0706	3.0216	2.6056	1.9966	1.6706	2.2986	1.0956	1.0766	2.8036	2.8966	3.1616
Heel at Max Righting Arm (deg)	45	45	45	45	45	45	45	45	45	45	45	45
Wind Static Heel (deg)	9.9896	10.3346	10.7031	14.3167	16.7033	22.0084	13.6731	22.1276	24.5875	10.3852	10.0379	11.6881
Righting Arm at Wind Static Heel (ft)	0.4702	0.469	0.4677	0.4548	0.4441	0.4161	0.457	0.4154	0.4007	0.4688	0.47	0.4641
Max Heel (deg)	31.5136	24.5005	18.5108	22.614	20.3031	25.0277	31.856	23.5452	24.398	33.2679	30.9311	27.9747
St. Immersed at Max Heel	6.979	5.976	5.976	6.979	14.997	14.997	14.997	14.997	14.997	8.318	6.979	6.979
Min Heel (deg)	-31.6798	-24.6104	-18.9848	-23.5103	-21.1699	-26.567	-32.1819	-23.6597	-26.193	-33.3345	-31.0733	-28.9022
St. Immersed at Min Heel	6.979	5.976	5.976	6.979	14.997	14.997	13.955	14.997	14.997	8.318	6.979	6.979
Max Heel total (deg)	26.5407	24.5005	18.5108	11.0029	2.5865	7.5996	18.9885	5.7353	7.9309	25.1015	25.2605	22.1936
St. Immersed at Max Heel total	17.003	5.976	5.976	17.003	17.5	17.5	17.5	17.5	17.5	17.003	17.003	17.003
Min Heel total (deg)	-26.2208	-24.6104	-18.9848	-11.5684	-2.5017	-8.7214	-19.1667	-5.7375	-9.3427	-24.8358	-25.1193	-22.917
St. Immersed at Min Heel total	17.003	5.976	5.976	17.003	17.5	17.5	17.5	17.5	17.5	17.003	17.003	17.003
Roll Back (deg)	9.1216	9.1216	9.1216	9.1216	9.1216	9.1216	9.1216	9.1216	9.1216	9.1216	9.1216	9.1216
GM (ft)	2.9701	3.1878	3.566	3.811	3.6434	2.0047	1.6752	0.6095	1.3745	2.7868	2.9701	4.2464
Righting Arm - Heeling Arm @ Max RA (ft)	2.715	2.828	2.779	2.363	1.754	1.428	2.056	0.853	0.834	2.561	2.654	2.919
Righting Arm at 30deg (ft)	1.9657	2.1787	2.3547	2.1217	1.5807	1.0467	1.4747	0.7957	0.7167	1.8487	1.9257	2.1857
Righting Energy, A1 (ft-rad)	0.3036	0.1377	0.0509	0.0704	0.0066	0.0022	0.1839	-0.002	-0.0004	0.3311	0.279	0.2166
Heeling Energy, A2 (ft-rad)	0.0424	0.0447	0.056	0.0629	0.0499	0.0444	0.0287	0.0261	0.0367	0.0401	0.0425	0.0568
Area Ratio, A1/A2	7.1585	3.0821	0.9089	1.1203	0.1332	0.0493	6.4042	-0.078	-0.0103	8.2602	6.5709	3.811
Righting Arm Ratio	0.159	0.1527	0.1548	0.1745	0.2224	0.2491	0.1988	0.3791	0.3721	0.1672	0.1623	0.1468
Positive Stability Range (deg)	87.7847	86.8791	84.5975	79.7631	78.8547	70.8031	86.8645	70.7232	56.0869	87.8692	87.7268	83.4224
Positive Stability Righting Energy (ft-rad)	2.5491	2.6867	2.778	2.4891	1.8709	1.201	1.8189	0.6848	0.6137	2.4013	2.5472	2.9108

Table 17. Damage Stability Evaluation Results for CG 47 With External 3' Double Hull Using Segmented Tank Geometry

	15% L Shell Opening Along Ship							Severe Weapons		Bottom Raking		
	St. 0-3	St. 3-6	St. 6-9	St. 9-12	St. 12-15	St. 15-18	St. 18-20	Symetric	Strb. Side	20%	40%	60%
Static Heel (deg)	1.2153	7.2587	16.5931	19.3726	21.2454	19.7804	0.2394	-0.1824	23.1214	1.6377	7.9976	13.5354
Maximum Righting Arm (ft)	2.9576	2.8976	2.5139	2.3529	1.8709	1.5706	2.2986	1.0747	0.8396	2.7806	2.6959	2.9069
Heel at Max Righting Arm (deg)	45	45	50	50	50	45	45	40	45	45	50	50
Wind Static Heel (deg)	9.9896	14.4385	20.3992	23.0933	25.4059	24.8998	13.6731	21.7633	29.3139	10.8296	15.5997	18.791
Righting Arm at Wind Static Heel (ft)	0.4702	0.4543	0.4257	0.4096	0.3954	0.3988	0.457	0.4175	0.3683	0.4672	0.4494	0.4339
Max Heel (deg)	31.5136	24.7485	19.5529	27.1834	26.7683	25.1323	31.856	20.8356	24.2949	33.3382	31.8507	30.8523
St. Immersed at Max Heel	6.979	5.976	5.976	6.979	14.997	14.997	14.997	17.001	14.997	8.318	6.979	6.979
Min Heel (deg)	-31.6798	-25.5997	-21.0619	-27.8889	-27.9412	-27.1618	-32.1819	-20.3086	-26.6647	-33.5086	-32.8242	-31.6561
St. Immersed at Min Heel	6.979	5.976	5.976	6.979	14.997	14.997	13.955	17.001	14.997	8.318	6.979	6.979
Max Heel total (deg)	26.5407	24.7485	19.5529	18.2678	11.2467	7.6413	18.9885	2.2746	8.2862	25.0502	25.2678	23.9406
St. Immersed at Max Heel total	17.003	5.976	5.976	17.003	17.5	17.5	17.5	20	17.5	17.003	17.003	17.003
Min Heel total (deg)	-26.2208	-25.5997	-21.0619	-18.7003	-12.238	-8.818	-19.1667	-2.204	-9.8065	-24.7579	-24.8556	-23.9678
St. Immersed at Min Heel total	17.003	5.976	5.976	17.003	17.5	17.5	17.5	20	18.003	17.003	17.003	17.003
Roll Back (deg)	9.1216	9.1216	9.1216	9.1216	9.1216	9.1216	9.1216	9.1216	9.1216	9.1216	9.1216	9.1216
GM (ft)	2.9701	3.3182	6.3405	5.3894	5.3362	3.3955	1.6752	0.6281	2.9183	2.7638	3.112	4.3309
Righting Arm - Heeling Arm @ Max RA (ft)	2.715	2.655	2.314	2.153	1.671	1.328	2.056	0.79	0.597	2.538	2.496	2.707
Righting Arm at 30deg (ft)	1.9657	1.9387	1.5607	1.2837	0.9127	0.8627	1.4747	0.7977	0.4117	1.8187	1.6047	1.5927
Righting Energy, A1 (ft-rad)	0.3036	0.0812	-0.004	0.0195	-0.0278	0.0002	0.1839	-0.0006	-0.0111	0.3211	0.1928	0.1339
Heeling Energy, A2 (ft-rad)	0.0424	0.0483	0.0582	0.0616	0.0625	0.0598	0.0287	0.0268	0.0469	0.04	0.0471	0.06
Area Ratio, A1/A2	7.1585	1.6822	-0.0681	0.3168	-0.4445	0.0039	6.4042	-0.0225	-0.2376	8.0264	4.0913	2.2293
Righting Arm Ratio	0.159	0.1568	0.1693	0.1741	0.2113	0.2539	0.1988	0.3885	0.4387	0.168	0.1667	0.1493
Positive Stability Range (deg)	87.7847	81.7413	72.4069	69.6274	67.7546	66.9262	86.8645	71.3543	45.8125	87.3623	81.0024	75.4646
Positive Stability Righting Energy (ft-rad)	2.5491	2.4637	2.1545	1.9847	1.5237	1.111	1.8189	0.6705	0.4033	2.3718	2.2605	2.5119

Table 18. Damage Stability Evaluation Results for CG 47 With External 6' Double Hull Using U-Tank Geometry

	15% L Shell Opening Along Ship							Severe Weapons		Bottom Raking		
	St. 0-3	St. 3-6	St. 6-9	St. 9-12	St. 12-15	St. 15-18	St. 18-20	Symetric	Strb. Side	20%	40%	60%
Static Heel (deg)	1.2191	1.9094	1.6854	2.1882	1.8103	12.2233	0.4271	0.5369	12.3542	1.1383	1.1186	1.0889
Maximum Righting Arm (ft)	2.6576	2.7356	2.7947	2.179	1.53	1.3867	2.1277	0.915	0.8707	2.5496	2.6816	2.9546
Heel at Max Righting Arm (deg)	45	45	40	35	35	40	40	35	40	45	45	45
Wind Static Heel (deg)	10.5275	10.2625	7.4289	9.1294	12.489	20.756	13.7116	20.8826	23.1408	10.8228	9.9765	8.2733
Righting Arm at Wind Static Heel (ft)	0.4884	0.4894	0.4962	0.4924	0.4811	0.4418	0.4765	0.441	0.4269	0.4873	0.4904	0.4943
Max Heel (deg)	29.1794	21.2022	12.6398	18.0215	13.3783	21.6308	29.5946	19.9853	21.019	30.575	25.7192	20.0603
St. Immersed at Max Heel	6.979	5.976	5.976	6.979	17.001	14.997	14.997	14.997	14.997	6.979	5.976	5.976
Min Heel (deg)	-29.3525	-21.2699	-12.7068	-18.1288	-13.1885	-22.343	-29.6189	-19.8267	-22.0049	-30.6498	-25.7303	-20.0842
St. Immersed at Min Heel	6.979	5.976	5.976	6.979	17.001	14.997	14.997	14.997	14.997	6.979	5.976	5.976
Max Heel total (deg)	26.505	21.2022	12.6398	7.5414	1.4961	5.0214	19.4453	2.393	5.4423	25.2457	25.7192	19.2903
St. Immersed at Max Heel total	17.003	5.976	5.976	17.003	17.002	18.003	17.003	20	18.003	17.003	5.976	17.003
Min Heel total (deg)	-26.2321	-21.2699	-12.7068	-7.4289	14.3458	-5.728	-19.3492	-2.0135	-6.0857	-24.9733	-25.7303	-19.6011
St. Immersed at Min Heel total	17.003	5.976	5.976	17.003	20	17.5	17.003	20	17.5	17.003	5.976	17.003
Roll Back (deg)	8.4901	8.4901	8.4901	8.4901	8.4901	8.4901	8.4901	8.4901	8.4901	8.4901	8.4901	8.4901
GM (ft)	2.867	3.2107	4.8952	3.3253	2.5003	2.2224	1.744	0.747	1.4661	2.718	3.0732	3.841
Righting Arm - Heeling Arm @ Max RA (ft)	2.405	2.483	2.498	1.84	1.191	1.09	1.831	0.576	0.574	2.297	2.429	2.702
Righting Arm at 30deg (ft)	2.0067	2.2107	2.4977	2.0937	1.4647	1.1097	1.5817	0.8327	0.7587	1.9137	2.0567	2.4407
Righting Energy, A1 (ft-rad)	0.2273	0.0861	0.0219	0.0646	-0.0001	-0.0143	0.1434	-0.0014	-0.0014	0.2478	0.1598	0.0952
Heeling Energy, A2 (ft-rad)	0.0367	0.0409	0.0536	0.0466	0.0307	0.0391	0.0262	0.0252	0.0308	0.0351	0.039	0.0417
Area Ratio, A1/A2	6.1969	2.1035	0.4098	1.3861	-0.0023	-0.3655	5.4819	-0.054	-0.0458	7.0657	4.0942	2.2807
Righting Arm Ratio	0.1838	0.1789	0.1776	0.226	0.3144	0.3186	0.224	0.4819	0.4903	0.1911	0.1829	0.1673
Positive Stability Range (deg)	78.0083	78.6818	84.1341	86.8118	81.024	56.4653	73.2738	57.065	45.048	77.4544	80.9911	87.9111
Positive Stability Righting Energy (ft-rad)	2.017	2.1704	2.4566	1.9896	1.2201	0.8023	1.434	0.4764	0.4059	1.9202	2.1327	2.7305

Table 19. Damage Stability Evaluation Results for CG 47 With External 6' Double Hull Using J-Tank Geometry

	15% L Shell Opening Along Ship							Severe Weapons		Bottom Raking		
	St. 0-3	St. 3-6	St. 6-9	St. 9-12	St. 12-15	St. 15-18	St. 18-20	Symetric	Strb. Side	20%	40%	60%
Static Heel (deg)	1.2191	7.9089	19.532	23.196	26.018	19.8585	0.4271	0.5866	21.1672	2.0834	13.8735	28.1111
Maximum Righting Arm (ft)	2.6576	2.4386	1.7186	1.0526	0.5787	1.1797	2.1277	0.92	0.656	2.5046	2.1166	1.4259
Heel at Max Righting Arm (deg)	45	45	45	45	40	40	40	35	35	45	45	50
Wind Static Heel (deg)	10.5275	15.3613	23.3521	27.4117	31.7683	25.2636	13.7116	20.8608	28.1024	11.6136	20.2967	31.2643
Righting Arm at Wind Static Heel (ft)	0.4884	0.4699	0.4256	0.3979	0.3651	0.4134	0.4765	0.4411	0.3929	0.4844	0.4446	0.3691
Max Heel (deg)	29.1794	22.6355	16.8576	20.7061	18.247	22.9852	29.5946	20.1129	22.7292	30.7352	27.741	24.4805
St. Immersed at Max Heel	6.979	5.976	5.976	6.979	14.997	14.997	14.997	14.997	14.997	8.318	5.976	5.976
Min Heel (deg)	-29.3525	-23.5969	-18.7959	-22.3126	-20.2876	-25.1307	-29.6189	-19.8226	-24.6912	-30.7734	-29.4795	-27.6469
St. Immersed at Min Heel	6.979	5.976	5.976	8.318	14.997	14.997	14.997	14.997	14.997	8.318	6.979	6.979
Max Heel total (deg)	26.505	22.6355	16.8576	11.0957	2.7695	7.6558	19.4453	2.723	8.6683	25.0829	25.5913	21.5128
St. Immersed at Max Heel total	17.003	5.976	5.976	17.003	17.5	17.5	17.003	20	17.5	17.003	17.003	17.003
Min Heel total (deg)	-26.2321	-23.5969	-18.7959	-12.0879	-2.9092	-9.4812	-19.3492	-2.7903	-9.8561	-24.8457	-25.2887	-22.9184
St. Immersed at Min Heel total	17.003	5.976	5.976	17.003	17.5	17.5	17.003	20	17.5	17.003	17.003	17.003
Roll Back (deg)	8.4901	8.4901	8.4901	8.4901	8.4901	8.4901	8.4901	8.4901	8.4901	8.4901	8.4901	8.4901
GM (ft)	2.867	3.2265	5.7561	6.3102	4.1828	3.2465	1.744	0.7814	3.2392	2.6951	3.4944	6.9673
Righting Arm - Heeling Arm @ Max RA (ft)	2.405	2.186	1.466	0.8	0.282	0.883	1.831	0.581	0.317	2.252	1.864	1.217
Righting Arm at 30deg (ft)	2.0067	1.8327	1.1087	0.6117	0.2907	0.8037	1.5817	0.8377	0.5007	1.8607	1.3187	0.2297
Righting Energy, A1 (ft-rad)	0.2273	0.0451	-0.0115	-0.0009	-0.0086	-0.008	0.1434	-0.0012	-0.0036	0.2344	0.0486	-0.0173
Heeling Energy, A2 (ft-rad)	0.0367	0.0448	0.0663	0.0618	0.0462	0.0526	0.0262	0.0251	0.0374	0.0345	0.0492	0.0391
Area Ratio, A1/A2	6.1969	1.0061	-0.1736	-0.015	-0.1869	-0.1515	5.4819	-0.0459	-0.0968	6.7854	0.9883	-0.4423
Righting Arm Ratio	0.1838	0.1927	0.2476	0.378	0.6309	0.3504	0.224	0.4794	0.5989	0.1934	0.2101	0.2589
Positive Stability Range (deg)	78.0083	71.6876	62.1515	59.9508	42.3216	47.1426	73.2738	56.9971	34.0265	76.3616	66.7095	60.8889
Positive Stability Righting Energy (ft-rad)	2.017	1.7874	1.1718	0.6778	0.2772	0.6013	1.434	0.4767	0.2546	1.8648	1.452	0.9801

Table 20. Damage Stability Evaluation Results for CG 47 With External 6' Double Hull Using Wing Tank Geometry

	15% L Shell Opening Along Ship							Severe Weapons		Bottom Raking		
	St. 0-3	St. 3-6	St. 6-9	St. 9-12	St. 12-15	St. 15-18	St. 18-20	Symetric	Strb. Side	20%	40%	60%
Static Heel (deg)	1.2191	1.9313	5.8895	12.471	14.3816	14.2428	0.4271	0.5369	15.0305	1.1383	2.0937	10.6807
Maximum Righting Arm (ft)	2.6576	2.7356	2.7877	2.1287	1.4407	1.3847	2.1277	0.915	0.8687	2.5506	2.6826	2.9526
Heel at Max Righting Arm (deg)	45	45	40	40	40	40	40	35	40	45	45	45
Wind Static Heel (deg)	10.5275	10.2618	10.7841	16.4834	19.3176	21.318	13.7116	20.8859	23.7158	10.8228	10.403	15.2172
Righting Arm at Wind Static Heel (ft)	0.4884	0.4894	0.4875	0.4642	0.4499	0.4383	0.4765	0.441	0.4233	0.4873	0.4889	0.4706
Max Heel (deg)	29.1794	21.1998	13.052	18.7234	15.1294	21.7576	29.5946	19.9849	21.1375	30.575	25.7595	20.4444
St. Immersed at Max Heel	6.979	5.976	5.976	6.979	15.999	14.997	14.997	14.997	14.997	6.979	5.976	5.976
Min Heel (deg)	-29.3525	-21.433	-13.956	-20.2959	-16.8961	-23.4998	-29.6189	-19.827	-22.9464	-30.6394	-26.3473	-22.2362
St. Immersed at Min Heel	6.979	5.976	5.976	6.979	14.997	14.997	14.997	14.997	14.997	6.979	5.976	5.976
Max Heel total (deg)	26.505	21.1998	13.052	8.7985	5.7272	5.6274	19.4453	2.393	6.1429	25.2457	25.7595	20.1734
St. Immersed at Max Heel total	17.003	5.976	5.976	17.003	17.002	18.003	17.003	20	17.5	17.003	5.976	17.003
Min Heel total (deg)	-26.2321	-21.433	-13.956	-9.4285	8.2716	-6.8661	-19.3492	-2.0149	-7.7156	-24.9969	-25.8927	-21.4969
St. Immersed at Min Heel total	17.003	5.976	5.976	17.003	20	17.5	17.003	20	17.5	17.003	17.003	17.003
Roll Back (deg)	8.4901	8.4901	8.4901	8.4901	8.4901	8.4901	8.4901	8.4901	8.4901	8.4901	8.4901	8.4901
GM (ft)	2.867	3.2337	5.6559	6.3821	4.6976	2.4745	1.744	0.747	2.4329	2.718	3.2566	5.9123
Righting Arm - Heeling Arm @ Max RA (ft)	2.405	2.483	2.491	1.832	1.144	1.088	1.831	0.576	0.572	2.298	2.43	2.7
Righting Arm at 30deg (ft)	2.0067	2.2107	2.4247	1.8437	1.2597	1.0997	1.5817	0.8327	0.7457	1.9147	2.0547	2.2947
Righting Energy, A1 (ft-rad)	0.2273	0.0862	-0.0235	-0.0165	-0.013	-0.0095	0.1434	-0.0014	-0.0035	0.2479	0.1561	0.0299
Heeling Energy, A2 (ft-rad)	0.0367	0.041	0.066	0.0689	0.0596	0.0428	0.0262	0.0253	0.0345	0.0351	0.0408	0.0704
Area Ratio, A1/A2	6.1969	2.103	-0.3561	-0.2388	-0.2173	-0.2217	5.4819	-0.0538	-0.1004	7.0696	3.8278	0.425
Righting Arm Ratio	0.1838	0.1789	0.1749	0.2181	0.3123	0.3165	0.224	0.4819	0.4873	0.1911	0.1822	0.1594
Positive Stability Range (deg)	78.0083	78.6599	79.93	76.529	68.4817	54.5197	73.2738	57.065	42.3541	77.4573	80.0208	78.3193
Positive Stability Righting Energy (ft-rad)	2.017	2.1709	2.3471	1.7362	1.0293	0.7888	1.434	0.4763	0.3944	1.9207	2.1215	2.5254

Table 21. Damage Stability Evaluation Results for CG 47 With External 6' Double Hull Using Segmented Tank Geometry

	15% L Shell Opening Along Ship							Severe Weapons		Bottom Raking		
	St. 0-3	St. 3-6	St. 6-9	St. 9-12	St. 12-15	St. 15-18	St. 18-20	Symetric	Strb. Side	20%	40%	60%
Static Heel (deg)	1.2191	10.8433	20.0863	22.7422	24.4674	20.3091	0.4271	0.1348	24.9562	2.0923	12.1896	17.0462
Maximum Righting Arm (ft)	2.6576	2.4776	1.8939	1.7629	1.2676	1.2217	2.1277	0.982	0.4707	2.5126	2.3926	2.6699
Heel at Max Righting Arm (deg)	45	45	50	50	45	40	40	35	40	45	45	50
Wind Static Heel (deg)	10.5275	16.6651	23.4249	25.6558	27.9826	24.9031	13.7116	18.0018	32.6274	11.6299	18.4256	20.9749
Righting Arm at Wind Static Heel (ft)	0.4884	0.4633	0.4251	0.4106	0.3938	0.4159	0.4765	0.4566	0.3582	0.4843	0.4544	0.4404
Max Heel (deg)	29.1794	21.6941	15.0342	23.3842	21.946	21.9792	29.5946	14.6555	21.0023	30.723	28.1767	26.6083
St. Immersed at Max Heel	6.979	5.976	5.976	6.979	14.997	14.997	14.997	17.001	14.997	8.318	6.979	5.976
Min Heel (deg)	-29.3525	-22.6122	-16.3971	-24.2534	-23.3316	-23.9743	-29.6189	-14.6936	-23.3483	-30.7734	-29.4795	-27.6891
St. Immersed at Min Heel	6.979	5.976	5.976	6.979	14.997	14.997	14.997	17.001	14.997	8.318	6.979	6.979
Max Heel total (deg)	26.505	21.6941	15.0342	16.5814	6.973	5.7627	19.4453	5.4209	6.0469	25.0901	25.5836	23.5212
St. Immersed at Max Heel total	17.003	5.976	5.976	17.003	17.5	17.5	17.003	17.002	17.5	17.003	17.003	17.003
Min Heel total (deg)	-26.2321	-22.6122	-16.3971	-17.136	-8.1612	-6.9748	-19.3492	9.4657	-7.5812	-24.8457	-25.2887	-23.3061
St. Immersed at Min Heel total	17.003	5.976	5.976	17.003	17.5	17.5	17.003	20	17.5	17.003	17.003	17.003
Roll Back (deg)	8.4901	8.4901	8.4901	8.4901	8.4901	8.4901	8.4901	8.4901	8.4901	8.4901	8.4901	8.4901
GM (ft)	2.867	4.2965	7.2957	8.3156	7.0665	5.1872	1.744	0.8502	3.5142	2.6836	3.8267	6.1686
Righting Arm - Heeling Arm @ Max RA (ft)	2.405	2.225	1.685	1.554	1.015	0.925	1.831	0.643	0.174	2.26	2.14	2.461
Righting Arm at 30deg (ft)	2.0067	1.8287	1.1527	0.9597	0.6157	0.8417	1.5817	0.9337	0.2787	1.8577	1.5907	1.6397
Righting Energy, A1 (ft-rad)	0.2273	0.0226	-0.0181	-0.0098	-0.006	-0.0119	0.1434	-0.0015	-0.001	0.2334	0.0819	0.0393
Heeling Energy, A2 (ft-rad)	0.0367	0.0516	0.0538	0.0338	0.0517	0.0618	0.0262	0.0251	0.0314	0.0345	0.0456	0.0635
Area Ratio, A1/A2	6.1969	0.4372	-0.3364	-0.2888	-0.1152	-0.1921	5.4819	-0.0588	-0.0315	6.7617	1.795	0.6181
Righting Arm Ratio	0.1838	0.187	0.2245	0.2329	0.3106	0.3404	0.224	0.4649	0.7611	0.1927	0.1899	0.165
Positive Stability Range (deg)	78.0083	70.541	68.9137	66.2578	63.5758	49.3896	73.2738	58.3924	27.8893	76.4142	70.3891	71.9538
Positive Stability Righting Energy (ft-rad)	2.017	1.8319	1.4622	1.3453	0.8681	0.6588	1.434	0.5365	0.147	1.8694	1.7212	2.1687

Table 22. Summary of Evaluation Results for Intact Case

	Original	3' Spacing	6' Spacing
U.S. Navy Criteria			
Area Ratio (140%, minimum)	465.0%	324.8%	159.9%
Righting Arm Ratio (60%, maximum)	0.235	0.210	0.177
USCG Criteria			
Metacenter, GM Limit (1.5, minimum)	**-0.69**	**-0.72**	**-0.74**
GZ at 30deg (0.2, minimum)	0.33	0.35	0.36
Max Righting Arm Heel (25, minimum)	25	20	15
Righting Energy to 30deg (0.055, minimum)	0.071	0.071	0.073
Righting Energy 30 to 40deg (0.03, minimum)	0.083	0.088	0.089
Righting Energy to 40deg or Max Heel (0.09, minimum)	0.114	0.080	0.055

NOTE: Shown in parenthesis are the value of the criteria and weather it is an upper (maximum) or lower (minimum) limit. Values in the table are the difference from the criteria. A lar indicates a characteristic beyond what the criteria calls for. Negative values indicate a criteria failure.

Table 23. Summary of Evaluation Results for 15%L Damage, Station 0 to Station 3

	Original and Internal Compartmentation	External 3' Spacing	External 6' Spacing
U.S. Navy Criteria			
Area Ratio (140%, minimum)	729.0%	635.7%	502.1%
Righting-Heeling Arm Difference (0.25, minimum)	2.819	2.472	2.162
Static Wind Loaded Heel (20, maximum)	11.26	10.45	9.79
Static Wind Loaded Heel (15, maximum)	6.26	5.45	4.79
USCG Criteria			
Static Heel (25, maximum)	24.38	24.29	24.22
Positive Righting Arm Range above Static Heel (20, minimum)	68.38	68.29	58.44
Righting Energy (0.0175, minimum)	0.930	0.764	0.601

NOTE: Shown in parenthesis are the value of the criteria and weather it is an upper (maximum) or lower (minimum) limit. Values in the table are the difference from the criteria. A larger value indicates a characteristic beyond what the criteria calls for. Negative values indicate a criteria failure.

Table 24. Summary of Evaluation Results for 15%L Damage, Station 3 to Station 6

		Internal								External							
		3ft Spacing				6ft Spacing				3ft Spacing				6ft Spacing			
	Original	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented
U.S. Navy Criteria																	
Area Ratio (140%, minimum)	455.7%	386.0%	605.9%	387.6%	688.1%	335.7%	714.9%	356.3%	659.2%	281.4%	482.6%	281.8%	607.4%	171.7%	605.3%	187.5%	768.7%
Righting-Heeling Arm Difference (0.25, minimum)	2.975	3.073	3.095	3.082	3.138	3.119	3.162	3.193	3.236	2.649	2.705	2.661	2.754	2.286	2.426	2.328	2.610
Static Wind Loaded Heel (20, maximum)	12.69	12.85	15.39	12.84	17.73	12.92	17.33	13.00	21.68	12.09	14.86	12.07	17.34	11.68	16.94	11.84	22.30
Static Wind Loaded Heel (15, maximum)	7.69	7.85	10.39	7.84	12.73	7.92	12.33	8.00	16.68	7.09	9.86	7.07	12.34	6.68	11.94	6.84	17.30
USCG Criteria																	
Static Heel (25, maximum)	25.95	25.40	28.27	25.40	30.59	25.11	30.04	25.14	33.87	25.56	28.73	25.54	31.18	25.32	31.31	25.34	35.43
Positive Righting Arm Range above Static Heel (20, minimum)	69.85	69.40	72.27	69.40	74.59	69.11	74.04	69.14	77.87	69.56	72.73	69.54	75.18	60.61	65.30	60.98	69.41
Righting Energy (0.0175, minimum)	0.980	1.015	1.033	1.018	1.068	1.032	1.068	1.057	1.141	0.830	0.852	0.833	0.884	0.673	0.729	0.692	0.814

NOTE: Shown in parenthesis are the value of the criteria and weather it is an upper (maximum) or lower (minimum) limit. Values in the table are the difference from the criteria. A larger value indicates a characteristic beyond what the criteria calls for. Negative values indicate a criteria failure.

Table 25. Summary of Evaluation Results for 15%L Damage, Station 6 to Station 9

		Internal								External							
		3ft Spacing				6ft Spacing				3ft Spacing				6ft Spacing			
	Original	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented
U.S. Navy Criteria																	
Area Ratio (140%, minimum)	324.4%	165.8%	815.1%	277.2%	745.9%	68.2%	1070.8%	341.0%	1800.3%	54.9%	677.7%	145.8%	685.2%	-85.8%	5168.8%	98.5%	-54397.2%
Righting-Heeling Arm Difference (0.25, minimum)	2.782	3.148	3.261	3.350	3.384	3.267	3.509	3.756	3.904	2.623	2.802	2.833	2.950	2.352	2.894	2.925	3.557
Static Wind Loaded Heel (20, maximum)	10.41	12.86	24.02	14.65	29.89	13.67	31.42	18.87	35.04	12.80	25.58	14.59	30.56	14.33	33.44	19.22	35.70
Static Wind Loaded Heel (15, maximum)	5.41	7.86	19.02	9.65	24.89	8.67	26.42	13.87	30.04	7.80	20.58	9.59	25.56	9.33	28.44	14.22	30.70
USCG Criteria																	
Static Heel (25, maximum)	26.29	25.03	36.55	26.79	39.79	24.65	41.94	29.54	43.44	25.57	37.87	27.38	40.57	25.24	43.50	29.65	44.25
Positive Righting Arm Range above Static Heel (20, minimum)	70.29	69.03	80.55	70.79	83.79	68.65	85.94	73.54	87.44	69.57	81.97	71.36	84.57	65.20	77.81	71.72	78.34
Righting Energy (0.0175, minimum)	0.931	1.080	1.172	1.159	1.295	1.138	1.319	1.354	1.552	0.869	0.975	0.948	1.089	0.769	1.026	0.984	1.280

NOTE: Shown in parenthesis are the value of the criteria and weather it is an upper (maximum) or lower (minimum) limit. Values in the table are the difference from the criteria. A larger value indicates a characteristic beyond what the criteria calls for. Negative values indicate a criteria failure.

Table 26. Summary of Evaluation Results for 15%L Damage, Station 9 to Station 12

		Internal								External							
		3ft Spacing				6ft Spacing				3ft Spacing				6ft Spacing			
	Original	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented
U.S. Navy Criteria																	
Area Ratio (140%, minimum)	318.2%	290.0%	1086.9%	718.6%	904.1%	214.0%	1288.2%	976.8%	1165.6%	143.5%	803.0%	620.3%	783.6%	32.8%	9628.0%	652.4%	5802.8%
Righting-Heeling Arm Difference (0.25, minimum)	2.570	2.722	3.054	3.267	3.091	2.689	3.369	3.754	3.687	2.129	2.583	2.713	2.649	1.605	2.766	2.854	3.282
Static Wind Loaded Heel (20, maximum)	7.40	9.80	27.06	17.94	30.05	11.26	36.70	25.69	36.23	9.31	28.84	17.53	30.68	11.25	37.75	25.75	36.82
Static Wind Loaded Heel (15, maximum)	2.40	4.80	22.06	12.94	25.05	6.26	31.70	20.69	31.23	4.31	23.84	12.53	25.68	6.25	32.75	20.75	31.82
USCG Criteria																	
Static Heel (25, maximum)	23.16	23.44	39.72	30.74	40.29	23.64	46.29	36.28	44.70	23.63	40.71	31.52	40.74	23.94	47.16	36.14	45.25
Positive Righting Arm Range above Static Heel (20, minimum)	67.16	67.44	79.72	74.74	84.29	67.64	86.29	80.28	88.70	67.63	84.71	75.52	84.74	67.94	81.87	80.14	79.99
Righting Energy (0.0176, minimum)	0.897	0.983	1.129	1.207	1.241	0.998	1.334	1.456	1.505	0.764	0.865	0.988	1.028	0.589	1.039	1.059	1.204

NOTE: Shown in parenthesis are the value of the criteria and weather it is an upper (maximum) or lower (minimum) limit. Values in the table are the difference from the criteria. A larger value indicates a characteristic beyond what the criteria calls for. Negative values indicate a criteria failure.

Table 27. Summary of Evaluation Results for 15%L Damage, Station 12 to Station 15

		Internal								External							
		3ft Spacing				6ft Spacing				3ft Spacing				6ft Spacing			
	Original	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented
U.S. Navy Criteria																	
Area Ratio (140%, minimum)	77.0%	15.1%	1110.4%	408.6%	846.5%	-57.7%	4276.3%	943.2%	3807.4%	-77.5%	784.5%	284.7%	714.0%	-139.7%	-16590.4%	403.5%	-31478.3%
Righting-Heeling Arm Difference (0.25, minimum)	2.052	2.076	2.426	2.551	2.601	1.977	2.761	2.999	3.227	1.500	2.037	2.003	2.206	0.942	2.206	2.073	2.861
Static Wind Loaded Heel (20, maximum)	4.64	6.00	26.89	15.48	32.18	6.35	39.34	25.00	38.41	5.80	28.58	13.97	32.64	7.51	39.83	25.98	38.60
Static Wind Loaded Heel (15, maximum)	-0.36	1.00	21.89	10.48	27.18	1.35	34.34	20.00	33.41	0.80	23.58	8.97	27.64	2.51	34.83	20.98	33.60
USCG Criteria																	
Static Heel (25, maximum)	22.97	23.54	42.40	31.20	43.30	23.71	49.89	38.95	47.19	22.98	42.76	32.01	43.41	23.70	49.73	38.00	47.77
Positive Righting Arm Range above Static Heel (20, minimum)	66.97	67.54	86.40	75.20	87.30	67.71	93.89	82.95	91.19	66.98	86.76	76.01	87.41	60.38	82.30	80.64	81.83
Righting Energy (0.0175, minimum)	0.749	0.766	0.980	0.970	1.104	0.751	1.181	1.197	1.381	0.566	0.786	0.756	0.900	0.352	0.865	0.777	1.105

NOTE: Shown in parenthesis are the value of the criteria and weather it is an upper (maximum) or lower (minimum) limit. Values in the table are the difference from the criteria. A larger value indicates a characteristic beyond what the criteria calls for. Negative values indicate a criteria failure.

Table 28. Summary of Evaluation Results for 15%L Damage, Station 15 to Station 18

	Internal									External							
		3ft Spacing				6ft Spacing				3ft Spacing				6ft Spacing			
	Original	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented
U.S. Navy Criteria																	
Area Ratio (140%, minimum)	499.2%	427.8%	1493.8%	706.2%	852.2%	333.5%	1140.4%	961.9%	849.1%	273.0%	1446.5%	449.2%	944.1%	88.2%	1131.0%	522.4%	894.3%
Righting-Heeling Arm Difference (0.25, minimum)	1.778	1.780	1.943	1.929	2.019	1.768	2.078	2.113	2.202	1.455	1.642	1.571	1.710	1.129	1.530	1.428	1.730
Static Wind Loaded Heel (20, maximum)	6.38	9.13	20.17	12.53	29.10	10.72	29.05	20.35	32.71	6.51	15.66	8.78	27.12	6.60	24.44	12.92	31.85
Static Wind Loaded Heel (15, maximum)	1.38	4.13	15.17	7.53	24.10	5.72	24.05	15.35	27.71	1.51	10.66	3.78	22.12	1.60	19.44	7.92	26.85
USCG Criteria																	
Static Heel (25, maximum)	40.18	38.24	43.18	38.89	44.26	37.17	45.44	40.60	45.14	36.94	42.15	37.54	43.74	35.23	43.67	37.46	44.51
Positive Righting Arm Range above Static Heel (20, minimum)	84.18	82.24	87.18	82.89	88.26	81.17	89.44	84.60	89.14	78.18	83.06	79.53	84.75	60.93	70.92	65.61	72.56
Righting Energy (0.0176, minimum)	0.642	0.662	0.741	0.718	0.804	0.673	0.823	0.816	0.922	0.472	0.553	0.514	0.609	0.339	0.494	0.436	0.601

NOTE: Shown in parenthesis are the value of the criteria and weather it is an upper (maximum) or lower (minimum) limit. Values in the table are the difference from the criteria. A larger value indicates a characteristic beyond what the criteria calls for. Negative values indicate a criteria failure.

Table 29. Summary of Evaluation Results for 15%L Damage, Station 18 to Station 20

	Original and Internal Compartmentation	External 3' Spacing	External 6' Spacing
U.S. Navy Criteria			
Area Ratio (140%, minimum)	585.2%	499.6%	396.5%
Righting-Heeling Arm Difference (0.25, minimum)	2.089	1.866	1.628
Static Wind Loaded Heel (20, maximum)	6.39	6.33	6.30
Static Wind Loaded Heel (15, maximum)	1.39	1.33	1.30
USCG Criteria			
Static Heel (25, maximum)	23.39	23.44	23.47
Positive Righting Arm Range above Static Heel (20, minimum)	67.39	66.20	52.74
Righting Energy (0.0175, minimum)	0.703	0.555	0.431

NOTE: Shown in parenthesis are the value of the criteria and weather it is an upper (maximum) or lower (minimum) limit. Values in the table are the difference from the criteria. A larger value indicates a characteristic beyond what the criteria calls for. Negative values indicate a criteria failure.

Table 30. Summary of Evaluation Results for Sever Weapons Damage, Starboard Side

		Internal								External							
		3ft Spacing				6ft Spacing				3ft Spacing				6ft Spacing			
	Original	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented
U.S. Navy Criteria																	
Area Ratio (140%, minimum)	-133.5%	-130.2%	-130.4%	-130.1%	-105.2%	-98.9%	-99.6%	-98.9%	-140.1%	-132.9%	-133.1%	-133.3%	-141.6%	-144.8%	-144.5%	-144.6%	-146.1%
Righting-Heeling Arm Difference (0.25, minimum)	0.764	0.925	0.925	0.926	0.913	0.942	0.940	0.942	1.076	0.600	0.600	0.600	0.536	0.323	0.321	0.322	0.399
Static Wind Loaded Heel (20, maximum)	-4.42	-2.02	-2.02	-2.02	-0.59	-0.58	-0.60	-0.58	2.66	-2.17	-2.17	-2.19	-1.82	-0.93	-0.94	-0.94	1.91
Static Wind Loaded Heel (15, maximum)	-9.42	-7.02	-7.02	-7.02	-5.59	-5.58	-5.60	-5.58	-2.34	-7.17	-7.17	-7.19	-6.82	-5.93	-5.94	-5.94	-3.09
USCG Criteria																	
Static Heel (25, maximum)	26.16	27.60	27.60	27.60	27.24	27.85	27.92	27.85	29.06	25.10	25.10	25.10	25.54	24.70	24.77	24.70	25.14
Positive Righting Arm Range above Static Heel (20, minimum)	70.16	71.60	71.60	71.60	71.24	71.85	71.92	71.85	73.06	50.96	50.96	50.96	51.42	37.24	37.31	37.25	38.43
Righting Energy (0.0175, minimum)	0.297	0.337	0.337	0.337	0.366	0.369	0.368	0.369	0.444	0.190	0.190	0.190	0.186	0.127	0.127	0.127	0.146

NOTE: Shown in parenthesis are the value of the criteria and weather it is an upper (maximum) or lower (minimum) limit. Values in the table are the difference from the criteria. A larger value indicates a characteristic beyond what the criteria calls for. Negative values indicate a criteria failure.

Table 31. Summary of Evaluation Results for Severe Weapons Damage, Port and Starboard

		Internal								External							
		3ft Spacing				6ft Spacing				3ft Spacing				6ft Spacing			
	Original	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented
U.S. Navy Criteria																	
Area Ratio (140%, minimum)	423.4%	407.7%	1283.5%	713.3%	1110.0%	288.0%	1295.7%	981.6%	3883.7%	208.1%	1313.7%	390.4%	1157.0%	48.5%	1315.9%	475.4%	3425.0%
Righting-Heeling Arm Difference (0.25, minimum)	1.125	1.174	1.403	1.350	1.492	1.204	1.845	1.621	1.816	0.888	1.138	1.022	1.221	0.844	1.138	0.975	1.350
Static Wind Loaded Heel (20, maximum)	8.12	11.10	23.82	14.36	32.71	12.97	31.36	22.38	37.69	7.48	18.40	10.08	30.34	6.59	26.23	14.01	36.46
Static Wind Loaded Heel (15, maximum)	3.12	6.10	18.82	9.36	27.71	7.97	26.36	17.38	32.69	2.48	13.40	5.08	25.34	1.59	21.23	9.01	31.46
USCG Criteria																	
Static Heel (25, maximum)	43.21	41.44	46.41	41.83	49.27	40.47	48.32	43.41	50.75	39.85	45.18	40.45	48.49	37.28	46.25	40.02	49.95
Positive Righting Arm Range above Static Heel (20, minimum)	87.21	85.44	90.41	85.83	93.27	84.47	92.32	87.41	94.75	68.62	75.20	70.60	78.77	53.53	66.12	59.74	70.83
Righting Energy (0.0175, minimum)	0.444	0.477	0.574	0.538	0.644	0.500	0.684	0.658	0.792	0.311	0.409	0.354	0.469	0.226	0.397	0.323	0.512

NOTE: Shown in parenthesis are the value of the criteria and weather it is an upper (maximum) or lower (minimum) limit. Values in the table are the difference from the criteria. A larger value indicates a characteristic beyond what the criteria calls for. Negative values indicate a criteria failure.

Table 32. Summary of Evaluation Results for 20%L Bottom Raking

		Internal								External							
		3ft Spacing				6ft Spacing				3ft Spacing				6ft Spacing			
	Original	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented
U.S. Navy Criteria																	
Area Ratio (140%, minimum)	869.7%	844.9%	894.1%	844.9%	894.1%	822.2%	915.2%	822.5%	915.2%	696.8%	746.0%	695.8%	746.0%	575.1%	643.1%	571.3%	643.1%
Righting-Heeling Arm Difference (0.25, minimum)	2.605	2.609	2.623	2.609	2.623	2.608	2.636	2.624	2.636	2.317	2.337	2.319	2.337	2.053	2.051	2.061	2.051
Static Wind Loaded Heel (20, maximum)	10.38	10.42	10.84	10.42	10.84	10.45	11.22	10.45	11.22	9.76	10.12	9.76	10.12	9.29	9.92	9.29	9.92
Static Wind Loaded Heel (15, maximum)	5.38	5.42	5.84	5.42	5.84	5.45	6.22	5.45	6.22	4.76	5.12	4.76	5.12	4.29	4.92	4.29	4.92
USCG Criteria																	
Static Heel (25, maximum)	24.10	24.08	24.60	24.08	24.60	24.05	25.00	24.05	25.00	24.07	24.56	24.07	24.56	24.03	24.96	24.03	24.96
Positive Righting Arm Range above Static Heel (20, minimum)	68.10	68.08	68.60	68.08	68.60	68.05	69.00	68.05	69.00	68.07	68.56	68.07	68.56	57.54	58.43	57.61	58.43
Righting Energy (0.0175, minimum)	0.863	0.865	0.871	0.865	0.871	0.866	0.878	0.870	0.878	0.715	0.721	0.716	0.721	0.570	0.582	0.571	0.582

NOTE: Shown in parenthesis are the value of the criteria and weather it is an upper (maximum) or lower (minimum) limit. Values in the table are the difference from the criteria. A larger value indicates a characteristic beyond what the criteria calls for. Negative values indicate a criteria failure.

Table 33. Summary of Evaluation Results for 40%L Bottom Raking

		Internal								External							
		3ft Spacing				6ft Spacing				3ft Spacing				6ft Spacing			
	Original	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented
U.S. Navy Criteria																	
Area Ratio (140%, minimum)	874.2%	870.0%	1252.7%	694.1%	997.0%	510.1%	1523.1%	643.7%	1108.7%	544.4%	1234.5%	581.0%	915.8%	285.7%	1530.1%	476.9%	933.8%
Righting-Heeling Arm Difference (0.25, minimum)	2.644	2.692	2.831	2.766	2.705	2.777	3.008	3.059	2.783	2.390	2.581	2.465	2.431	2.169	2.557	2.439	2.241
Static Wind Loaded Heel (20, maximum)	10.67	10.82	16.64	10.97	12.83	11.28	21.94	12.67	14.73	10.15	16.49	10.33	12.31	10.16	22.93	11.76	14.21
Static Wind Loaded Heel (15, maximum)	5.67	5.82	11.64	5.97	7.83	6.28	16.94	7.67	9.73	5.15	11.49	5.33	7.31	5.16	17.93	6.76	9.21
USCG Criteria																	
Static Heel (25, maximum)	24.31	24.13	30.62	24.21	26.68	24.15	35.42	25.19	28.64	24.11	31.21	24.20	26.89	24.13	37.26	25.23	29.53
Positive Righting Arm Range above Static Heel (20, minimum)	68.31	68.13	74.62	68.21	70.68	68.15	79.42	69.19	72.64	68.11	75.21	68.20	70.89	60.91	71.60	63.56	63.38
Righting Energy (0.0175, minimum)	0.874	0.901	0.971	0.924	0.907	0.940	1.066	1.033	0.942	0.752	0.828	0.776	0.759	0.629	0.799	0.717	0.657

NOTE: Shown in parenthesis are the value of the criteria and weather it is an upper (maximum) or lower (minimum) limit. Values in the table are the difference from the criteria. A larger value indicates a characteristic beyond what the criteria calls for. Negative values indicate a criteria failure.

Table 34. Summary of Evaluation Results for 60%L Bottom Raking

		Internal								External							
		3ft Spacing				6ft Spacing				3ft Spacing				6ft Spacing			
	Original	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented	U-Tank	J-Tank	Wing Tank	Segmented
U.S. Navy Criteria																	
Area Ratio (140%, minimum)	909.2%	624.8%	1889.3%	932.5%	1433.9%	234.8%	6359.9%	1044.6%	1552.4%	419.4%	1916.0%	854.0%	1451.0%	88.0%	##############	837.1%	1687.4%
Righting-Heeling Arm Difference (0.25, minimum)	2.895	2.795	3.149	3.385	3.055	3.002	3.716	4.270	3.427	2.469	3.023	3.086	2.866	2.300	3.502	3.648	3.194
Static Wind Loaded Heel (20, maximum)	11.85	11.11	30.95	17.14	21.30	12.36	43.49	25.15	25.19	10.51	31.57	16.59	21.63	11.48	44.71	24.23	26.81
Static Wind Loaded Heel (15, maximum)	6.85	6.11	25.95	12.14	16.30	7.36	38.49	20.15	20.19	5.51	26.57	11.59	16.63	6.48	39.71	19.23	21.81
USCG Criteria																	
Static Heel (25, maximum)	24.70	24.15	42.71	29.20	33.56	24.25	52.50	35.36	36.23	24.15	43.46	29.13	34.32	24.25	53.35	34.94	38.02
Positive Righting Arm Range above Static Heel (20, minimum)	64.70	64.15	82.71	69.20	73.56	64.25	92.50	75.36	76.23	64.15	83.46	69.13	74.32	64.25	88.74	74.94	73.01
Righting Energy (0.0175, minimum)	0.922	0.924	1.184	1.149	1.062	1.027	1.544	1.549	1.220	0.788	1.079	1.022	0.952	0.745	1.359	1.272	1.016

NOTE: Shown in parenthesis are the value of the criteria and weather it is an upper (maximum) or lower (minimum) limit. Values in the table are the difference from the criteria. A larger value indicates a characteristic beyond what the criteria calls for. Negative values indicate a criteria failure.

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4. Code of Federal Regulations, Chapter 46, Sub-Chapter D, Parts 1 through 40 and 170 through 174.

5. "Principles of Naval Architecture - Volume I: Stability and Strength", Edward V. Lewis, editor, The Society of Naval Architects and Marine Engineers, Jersey City, N.J., 1988.